NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

OPERATIONAL EVALUATION OF SURVEILLANCE EFFECTIVENESS FOR AIRBORNE SEARCH OF MARITIME REGIONS

by

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March, 1995

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE March 1995	3. REPORT TYPE AND DATES COVERED Master's Thesis	
4. TITLE AND SUBTITLE OPERATIONAL EVALUATION OF SURVEILLANCE EFFECTIVENESS FOR AIRBORNE SEARCH OF MARITIME REGIONS			5. FUNDING NUMBERS
6. AUTHOR(S) Johnston, David, L.			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

Airborne maritime surveillance missions are time consuming, resource intensive activities, that must be carefully planned if poor utilization of highly expensive assets is to be avoided. This thesis develops a decision aid to provide aircraft tasking authorities with accurate estimates of target detection probabilities for different size search areas, using the surface traffic characteristics and predicted sensor performance for the area of operations. The decision aid uses simulation to evaluate estimates of surveillance effectiveness to a level of accuracy and sophistication not previously available. Surveillance estimates are calculated using mission-specific aircraft, sensor, and scenario information. The model can be utilized for a wide variety of aircraft/sensor combinations and blue water mission scenarios.

Surveillance estimates are presented graphically for each evaluated search area size. This facilitates the selection of the correct size to achieve a desired level of surveillance effectiveness or provides a measure of the aircraft's surveillance effectiveness for a given size search area.

14. SUBJECT TERMS Surveillance, Maritime Patrol, Radar Search, Search Effectiveness, Simulation			15. NUMBER OF PAGES 88
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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by

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March 1995

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ABSTRACT

Airborne maritime surveillance missions are time consuming, resource intensive activities, that must be carefully planned if poor utilization of highly expensive assets is to be avoided. This thesis develops a decision aid to provide aircraft tasking authorities with accurate estimates of target detection probabilities for different size search areas, using the surface traffic characteristics and predicted sensor performance for the area of operations. The decision aid uses simulation to evaluate estimates of surveillance effectiveness to a level of accuracy and sophistication not previously available. Surveillance estimates are calculated using mission-specific aircraft, sensor, and scenario information. The model can be utilized for a wide variety of aircraft/sensor combinations and blue water mission scenarios.

Surveillance estimates are presented graphically for each evaluated search area size. This facilitates the selection of the correct area size to achieve a desired level of surveillance effectiveness or provides a measure of the aircraft's surveillance effectiveness for a given sized search area.

THESIS DISCLAIMER

The reader is cautioned that the computer program developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure the program is free of computational and logic errors, it cannot be considered validated. Any application of this program without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

The location and identity of maritime vessels within a particular region can be critical to operations conducted by the military during times of peace or conflict, and to civil agencies involved with search and rescue, narcotic interdiction, and offshore economic resource protection. Airborne surveillance of maritime regions is an efficient and highly effective means to determine surface traffic information over a large area. Surveillance assets are limited in numbers and availability, and are expensive to operate.

Asset availability and cost constraints necessitate the efficient employment of surveillance aircraft. Effective utilization of aircraft commences with the assignment of a search area to each aircraft type that is commensurate with the:

- aircraft's physical performance, principally endurance and patrol speed;
- aircraft's on-station sensor performance;
- level to which each contact must be localized and identified (i.e., mission requirements);
- anticipated surface traffic levels in the region.

Improved aircraft utilization can be achieved by providing the mission tasking authority with an accurate estimate of target detection probabilities for different size search areas. This thesis documents the development of a decision aid that addresses the search area allocation problem, using the surface traffic characteristics and predicted sensor performance for the area of operations.

The principle element of the decision aid is a model that uses simulation to provide quantitative estimates of surveillance effectiveness to a level of accuracy and sophistication not previously available. Surveillance estimates are calculated using mission-specific aircraft, sensor, and scenario information. Accurate forecasting of aircraft surveillance radar to determine vessel detection ranges is achieved using an innovative adaptation of the Naval Command, Control and Ocean Surveillance Center (NCCOSC) Engineer's Refractive Effects Prediction System (EREPS) program. This ensures the sensor data used by the simulation is based on a credible estimate of radar performance in

the local environmental conditions. Additionally, the model can evaluate surveillance effectiveness for sensors other than radar.

The simulation accurately models the critical phases of a surveillance patrol with realistic aircraft performance and search methodologies. Sensor performance and aircraft movement are dynamically evaluated in three dimensions. The model can be utilized for a wide variety of aircraft/sensor combinations and blue water mission scenarios. Data files allow these parameters to be manipulated quickly and conveniently.

Surveillance estimates are presented graphically for each evaluated search area size. This facilitates the selection of the correct area size to achieve a desired level of surveillance effectiveness or provides a measure of the aircraft's surveillance effectiveness for a given sized search area.

I. INTRODUCTION

A. PROBLEM STATEMENT

The location and identity of maritime vessels within a particular region can be critical to operations conducted by the military during times of peace or conflict, and to civil agencies involved with search and rescue, narcotic interdiction, and offshore economic resource protection. Airborne surveillance of maritime regions is an efficient and highly effective means to determine surface traffic information over a large area. Surveillance assets are, however, limited in numbers, availability and are expensive to operate.

Asset availability and cost constraints necessitate the efficient employment of surveillance aircraft. Inadequate allocation of resources to search a desired area will result in poor coverage of the search region, and may preclude achievement of the mission. Conversely, over-allocation of resources is wasteful and may deny the employment of assets for other tasking. Effective utilization of aircraft commences with the assignment of a search area to each aircraft type that is commensurate with the:

- aircraft's physical performance, principally endurance and patrol speed;
- aircraft's on-station sensor performance;
- level to which each contact must be localized and identified (i.e., mission requirements); and
- anticipated surface traffic levels in the region.

B. THESIS OBJECTIVE

The objective of this thesis is to provide a decision aid to assist the effective and efficient employment of surface surveillance aircraft tasked to locate and identify maritime vessels. Improved aircraft employment can be achieved by providing the mission tasking authority with an accurate estimate of target detection probabilities for different size search areas. These estimates need to be based on predicted sensor performance in the environmental conditions forecast for the area of operations. Additionally, the decision aid should be sufficiently versatile to permit its employment for a large variety of aircraft/sensor combinations and varying mission scenarios.

C. THESIS PREVIEW

1. Simulation vs. Analytic Modeling

Analytic techniques are available to model a platform searching an area for multiple targets. Washburn (1989, p.2-4) describes two methods, exhaustive search and random search, that can be used to provide upper and lower bounds on target detection probabilities as a function of search area coverage. The suitability of these models for maritime surface surveillance mission planning is limited. Assumptions made in the construction of the model and the model's inability to incorporate important constraints to aircraft detection capability impose significant limitations. Examples of these limitations include:

- the target is stationary relative to the search platform, this is not true in the case of a helicopter searching for a fast surface vessel;
- search scenarios require the aircraft to achieve a stipulated target identification level where each level will impose a minimum target closure range and altitude;
- sensor ranges stay constant, even after the aircraft altitude changes;
- targets are all the same size and have identical sensor signatures;
- no effects from targets leaving the search area and new targets entering the search area.

Discrete event simulation provides a means to model realistic interactions that may be too complex to be evaluated analytically. This study employs a computer-based simulation (described in Chapter IV) to process a surveillance model numerically, from which data is gathered to estimate the desired real-world parameters. The simulation is enhanced through the use of graphics to provide insight and a visual appreciation of the interactions occurring within the model.

2. Environmental Model for Sensor Performance

The principle sensor used by most aircraft for the detection of surface vessels is radar. As discussed in the following chapter, radar detection ranges can be significantly influenced by a variety of environmental conditions. These effects must be quantified to calculate true sensor ranges. The Engineer's Refractive Effects Prediction System

(EREPS) developed by the Naval Command, Control and Ocean Surveillance Center (NCCOSC) is employed to provide radar detection ranges for the simulation because it:

- provides sophisticated tools to assess the electromagnetic (EM) propagation effects of the lower atmosphere on radar systems;
- is periodically revised and upgraded by NCCOSC to incorporate improvements in propagation theories;
- is either currently in use or is readily available to military aircraft mission planning authorities;
- is a stand-alone IBM-PC based system that requires minimal training to achieve competent use.

The decision to maintain the radar atmospheric effects model and the search area surveillance model as two separate entities is deliberate. Merging the two models into a single simulation program will result in the decision aid becoming less accurate for radar search applications if improvements in EM propagation forecasting are not simultaneously encoded into the simulation. Using separate models avoids unnecessary duplication of effort. A detailed description of EREPS and its application to the aircraft surface surveillance problem is presented in Chapter III.

II. AIRBORNE RADAR SEARCH

An accurate estimate of an aircraft's maximum sensor detection range against targets of various sizes, for various patrol altitudes, is a fundamental input to the simulation surveillance model if target detection probabilities are to be assessed realistically. This chapter outlines the factors that determine the maximum radar range with an emphasis on those parameters that cannot be estimated until the mission type and geographic location have been established.

A. RADAR RANGE EQUATION

The maximum radar range R_{max} is the distance beyond which the target cannot be detected. The fundamental form of the radar equation for a monostatic pulse radar is

$$R_{max} = \left[\frac{P_t \, G^2 \lambda^2 \sigma}{(4\pi)^3 \, (S/N)_{min}} \right]^{1/4} \qquad (1)$$

where

P_t = transmitted power, watts
G = antenna gain
λ = signal wavelength, meters
σ = target radar cross section, meters^2
$(S / N)_{min}$ = minimum signal to noise ratio

This equation does not predict the range performance of actual radar equipment to a satisfactory degree of accuracy (Skolnick, 1980, p. 15). Inaccuracies are introduced partly from the exclusion of factors representing various system losses and the effect of meteorological conditions along the propagation path. An expanded range equation that incorporates these factors is provided by Blake (1986, p. 17)

$$R_{max} = \left[\frac{P_t \, G^2 \lambda^2}{(4\pi)^3 \, (S/N)_{min} \, k \, T_s \, B_n \, L} \times \sigma \, F^4 \right]^{1/4} \qquad (2)$$

where

k = Boltzmann's constant
T_s = system noise temperature, degrees kelvin
B_n = receiver noise bandwidth, Hz
F = pattern propagation factor
L = system losses

Equation 2 has been separated into two expressions to indicate those factors that can be considered fixed or variable, respectively, on each search mission a radar is used. Factors in the first expression represent the physical capabilities and specifications of the radar that are determined by the design parameters of the equipment. The second expression describes the performance variables that are mission dependent. These variables are considerably more difficult to estimate with precision, yet they are essential for an accurate calculation of the maximum radar range. Pattern propagation factor is determined by the meteorological environment in which the radar operates. Target Radar Cross Section (RCS) is unique to each platform illuminated by the radar.

B. PATTERN PROPAGATION EFFECTS

In the simplest case, EM wave propagation is the transmission of a wave in free space. In free space an EM wave front spreads uniformly in all directions from the transmitter without influence from the earth's atmosphere. Free space conditions are not applicable to radar transmissions from an aircraft conducting maritime surveillance. The propagation of radar waves from an aircraft are affected by the earth's surface and its atmosphere. Free space radar performance is modified by the:

- refraction caused by an inhomogeneous atmosphere;
- reflection from the earth's surface, ocean, rain etc.;
- attenuation from gases constituting the atmosphere; and
- scattering of EM energy from the surface of the earth.

1. Refraction

Refraction refers to the property of a medium to bend an EM wave as it passes through that medium. A measure of the amount of refraction is the index of refraction, called refractivity. For microwave frequencies, refractivity is a function of atmospheric pressure, temperature, and relative humidity In free space an EM wave will travel in a straight line because the index of refraction is the same everywhere. In normal conditions within the earth's atmosphere, pressure and water vapor content decrease rapidly with height, while temperature decreases slowly with height. This causes the index of

refraction to decrease with increasing altitude. Therefore the propagation wave will be bent downward from a straight line as shown in Figure 1. This has the effect of extending the radar horizon beyond the visual horizon.

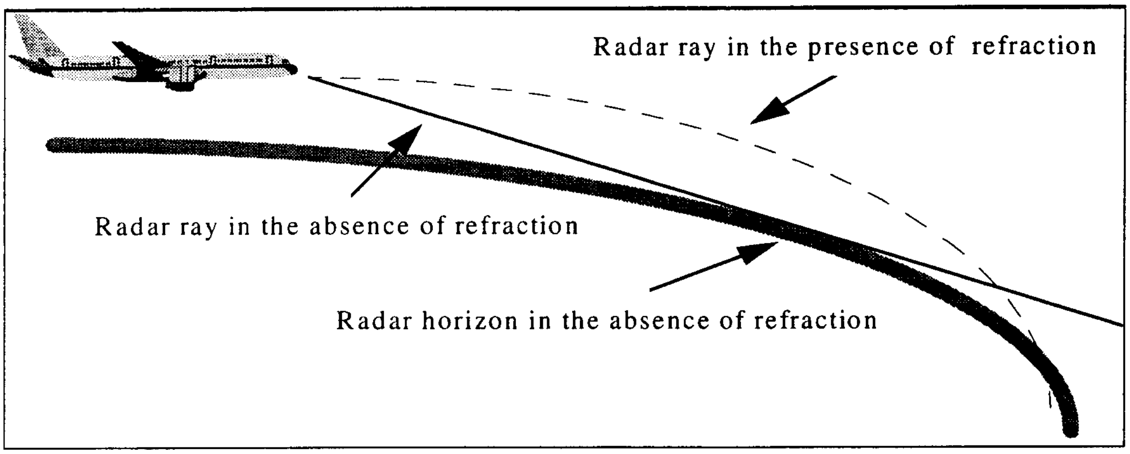


Figure 1. Radar Ray Path due to Refraction.

In standard refractivity conditions the radar horizon is calculated by

$$R_{horizon} = \sqrt{2kah_1 + h_1^2} + \sqrt{2kah_2 + h_2^2} \tag{3}$$

where

k = 1.33 (effective earth radius)
a = 3440 nmi (actual earth radius)
h_1 = height of radar antenna, nmi
h_2 = height of target, nmi

In many areas around the world the refractive index profile as a function of altitude departs drastically from the behavior associated with the standard atmosphere. Such conditions result in anomalous propagation of EM waves and can have an enormous influence on radar ranges.

2. Subrefraction

If the temperature and humidity conditions result in an increasing value of N with altitude, the EM wave will be bent upward causing radar energy to travel away from the

earth. This condition is termed subrefraction and results in reduced detection ranges for airborne platforms from that normally experienced (Figure 2).

3. Superrefraction

The existence of a temperature inversion (temperature increases with height) or a rapid decrease of water vapor with height will cause the propagating wave to be bent downward more than normal. Superrefraction can result in extended ranges when the radius of curvature of the wave path approaches the radius of curvature of the earth.

4. Trapping

If the refractivity gradient decreases beyond the critical gradient the radius of curvature of the wave will become smaller than that of the earth. This occurs when the index of refraction decreases rapidly with increasing altitude. In these conditions the EM wave will strike the earth's surface and be refracted back up, only to be bent down again.

A refractive index of this magnitude can exist only within a finite altitude region. These regions or ducts allow EM energy to propagate over great ranges. An EM wave will be trapped within a duct only if the angle the radar ray makes with the duct is small, generally less than half of one degree. To take advantage of the extended ranges possible within a duct, the altitude of both radar and target must be near that of the duct and the thickness (vertical extent) of the duct great enough in relation to the EM wavelength.

Trapping gradients can create three principle types of ducts. Of these only two, surface-based and elevated ducts, warrant consideration by aircraft due to practical limitations on the aircraft's altitude. Surface-based ducts occur when the air aloft is exceptionally warm and dry compared with the air at the earth's surface. The world average duct height extends to 280 feet, although heights up to 1000 feet are common. Radar systems operating near the earth surface can experience tremendously extended ranges for all frequencies above VHF.

Elevated ducts can trap rays only from an elevated source and are most important when assessing airborne radar performance. Radars located above the trapping layer will encounter combinations of ranges and altitudes into which no rays can penetrate creating

holes in the radar coverage. Aircraft located within an elevated duct will experience a reduced surface detection capability. Elevated ducts can occur more than 50% of the time in many areas around the world at altitudes up to several miles.

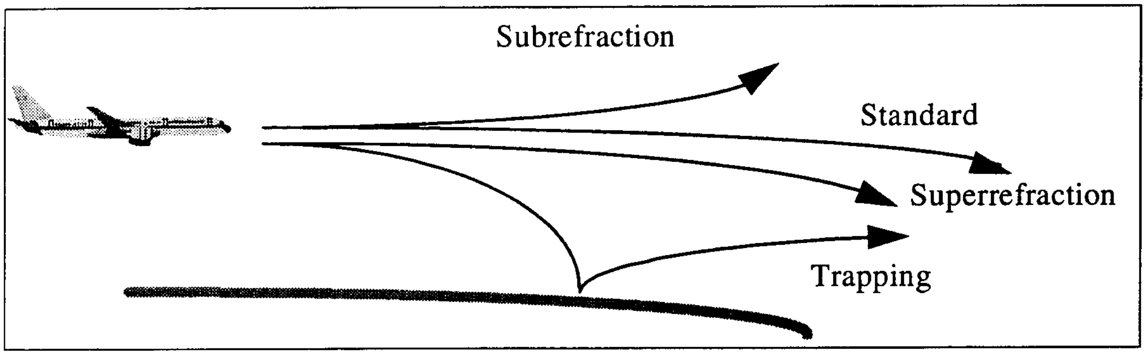


Figure 2. Refractive Conditions.

5. Attenuation

The attenuation of radar energy by absorption loss is important when calculating maximum detection ranges of radar systems with frequencies above one Ghz. Attenuation occurs when radar energy is absorbed as heat by oxygen and water vapor molecules. Propagation absorption loss increases with range and decreases with altitude.

6. Sea Clutter

The presence of sea clutter masks the existence of targets of interest and can significantly increase the difficulty of detection. Radar echo from the sea surface is dependent upon a combination of meteorological and radar parameters. Clutter is a function of wave height, wind speed, the length of time and fetch over which the wind has been blowing, and the direction of the waves relative to that of the radar beam. Important radar parameters include radar frequency, polarization, and the grazing angle (described in Figure 3).

The magnitude of sea clutter is highly dependent on grazing angle and as shown in Figure 4 is categorized into three areas. At near normal grazing angles the backscatter signal is larger when the sea is smooth. This region is sometimes referred to as quasi-

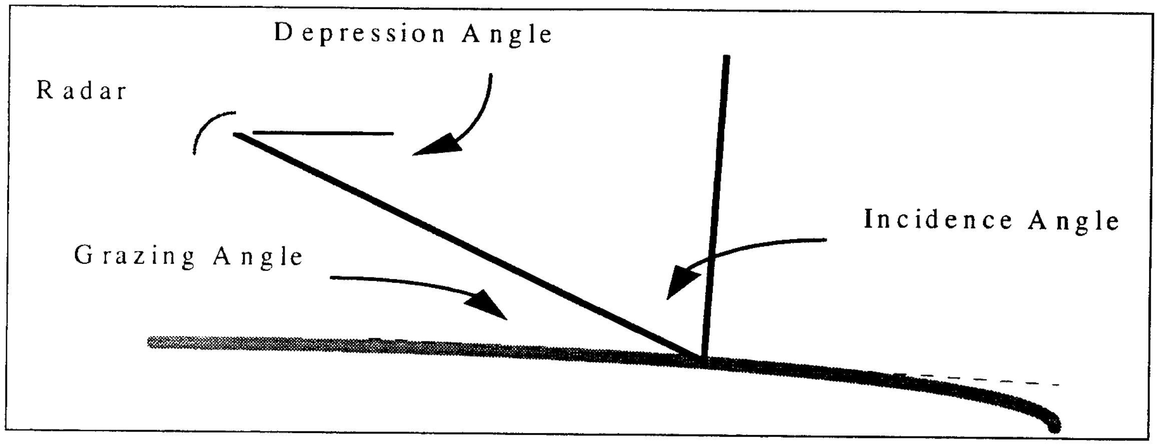


Figure 3. Surface Clutter Angles.

specular as the radar echo is the result of specular scatter from surfaces oriented perpendicular to the direction of the radar. Clutter return decreases as the grazing angle decreases and as the sea state increases. At a transition angle (approximately 60 degrees)the dependence reverses; sea clutter increases with increasing sea roughness. Within the plateau region the dependence of clutter on grazing angle is less steep. Below the plateau region the dependence of grazing angle becomes steep again (Blake, 1986, p. 309). The presence of ducting can result in greatly increased levels of sea clutter from ranges normally well beyond the horizon.

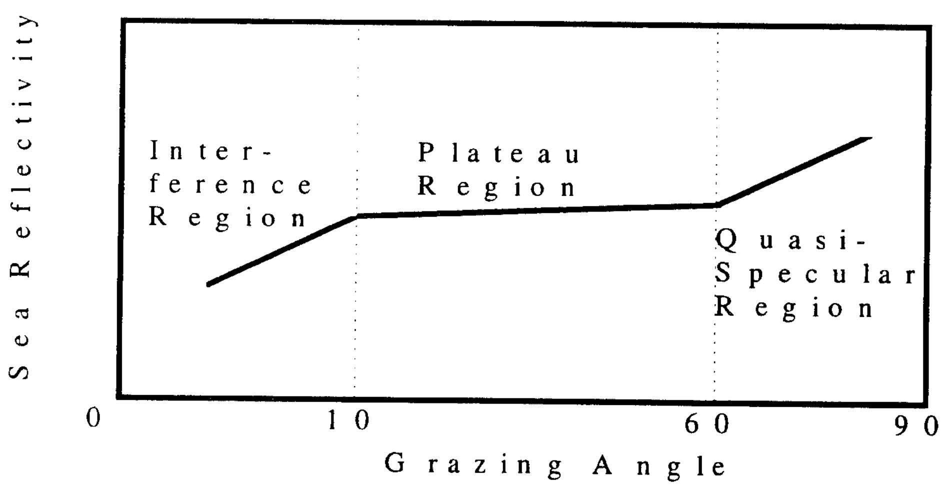


Figure 4. Sea Reflectivity vs. Grazing Angle.

C. TARGET RADAR CROSS SECTION

A target's RCS is a term used to describe the EM signal scattering efficiency of the target. The magnitude of the cross section σ has the same effect on the detection range as transmitter power, pulse length, and antenna gain. In principle, the RCS properties of targets can be calculated as a function of target size, shape, construction material, radar frequency, aspect angle, and radar wave polarization. In practice, measurement is very difficult as actual targets (like ships) are composed of many individual scattering points, each of which have different scattering properties.

Estimating the RCS of a ship is further complicated by the presence of the reflecting sea surface and when the radar range is near the horizon, the horizon effect (shadowing of the target by the earth's curvature) must be considered. Currently ship RCS is measured by illuminating a ship by radar on a test range or through the use of scale models. Neither of these techniques are of use to the practitioner attempting to estimate RCS.

Skolnick (1980, p. 43) developed an expression for estimating ship RCS based on a series of measurements taken on a variety of naval ships. This estimate is valid only for low altitude radars and is not applicable for airborne radars. Skolnick further suggests that when no better information is available, an order of magnitude estimate of RCS can be made by taking the ship displacement in tons to be equal to its cross section in square meters.

III. EREPS ATMOSPHERIC PROPAGATION MODEL

The radar range equation described in Chapter II provides a concise representation of the factors that determine the maximum range. The apparent simplicity of the range formula is misleading as many of the variables represent highly complex expressions. For most people, any attempt to numerically calculate the expressions by hand would prove to be prone to errors and extremely laborious.

The recent development of range estimation software has provided a viable means for practitioners to gain timely access to this information. This chapter introduces the EREPS system and describes it's adaptation, employment and limitations when applied to the aircraft surveillance problem.

A. SYSTEM DESCRIPTION

EREPS is a system of individual stand-alone IBM/PC compatible programs designed to assess the effects of the lower atmosphere on EM propagation for radar, electronic warfare or communication systems. The current version EREPS 3.0 requires at least a PC/XT class machine with a graphics capability that is EGA standard or better.

The EREPS models account for effects from optical interference, diffraction, tropospheric scatter, refraction, evaporation and surfaced based ducting, and water vapor absorption. Individual models are categorized by the analysis function they perform. The following models are available.

- PROPR - Generates a display of propagation loss, propagation factor, or radar signal-to-noise ratio versus range under a variety of environmental conditions from which signal levels relative to a specified threshold or maximum free space range can be determined.
- PROPH - Provides a display similar to PROPR except the independent plot variable is height.
- COVER - Provides a height-versus-range display showing the area where signal levels meet or exceed specified thresholds.
- RAYS - Displays altitude-versus-range trajectories of a series of rays for specified refractive-index profiles and includes an option to display altitude error relative to a standard atmosphere.

- SDS - Displays an annual climatological summary of evaporation duct, surface-based duct and other meteorological parameters. (NCCOSC Technical Document 2648, 1994)

B. PROPR MODEL

The capability to determine the maximum radar range is provided by the PROPR model using the propagation factor versus range display option. Propagation factor is numerically calculated as the ratio of the actual EM field strength at a point in space to the field strength that would exist at the same range under free space conditions. Radar detection is possible only when the propagation factor exceeds the displayed radar detection threshold. EREPS determines the propagation factor and radar detection thresholds using the environmental conditions and radar system parameters input by the user. Figure 5 is a snapshot of the graphic displayed by the PROPR model. In this example the performance of a surface radar is evaluated in conditions where no surface or evaporative duct exists (EVD and SBD heights are zero). The maximum radar range (12 nmi) is the greatest range for which the propagation factor exceeds the detection threshold. The data to the right of the graph partially describes the system parameters used to determine threshold levels. PROPR data input requirements will be discussed in more detail shortly.

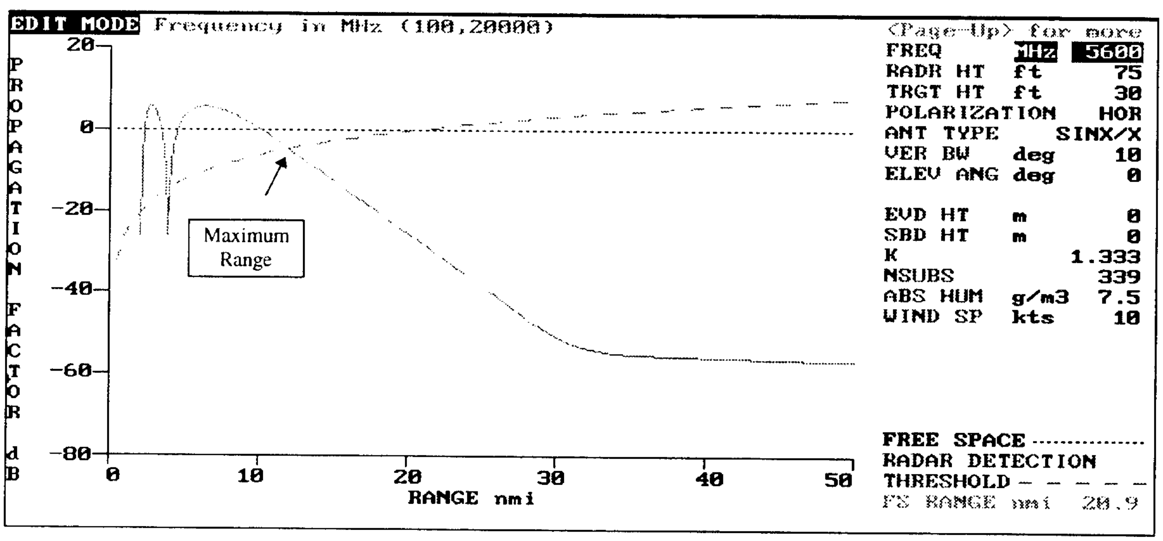


Figure 5. PROPR Graphic Display.

C. ADAPTATION OF PROPR MODEL FOR AIRBORNE RADAR

The PROPR model is designed primarily to calculate the effects of the lower atmosphere on surface-based radars employed against air or surface targets. Accordingly several of the radar parameter input fields have preset bounds on their range (e.g., radar height is limited to 0 - 300 ft) that appear to considerably limit the suitability of the model for employment by aircraft. These restrictions can be circumvented by reversing the geometry of the radar and the target.

In terms of EM propagation, the detection of surface vessels by an airborne radar is essentially equivalent to the detection of an airborne platform by a surface radar if the airborne target is assigned the physical characteristics associated with a ship (e.g., RCS). This relationship exists because the two-way EM ray path from air to surface is the same as from surface to air except for the interchange of direction of propagation, which does not effect the propagation characteristics. Using an appropriate translation of physical and system parameters this result can be exploited in the PROPR model by assigning aircraft radar parameters to the surface platform and surface vessel physical characteristics to the target.

Reversing the radar-target geometry is not without some penalty. As discussed in Chapter II, an aircraft searching for a surface contact will experience some loss in detection capability due to the presence of sea clutter. This degradation is not captured in the reversed model as sea clutter does not normally influence surface radar detection capability against medium to high altitude targets. The ability of modern radar to suppress the effects of clutter minimizes the modeling inaccuracies imposed by this result.

D. PROPR USER INPUT PARAMETERS

A numerical evaluation of the maximum detection range of the surveillance aircraft against targets of different sizes, with the aircraft at various altitudes is a fundamental input to the surveillance model. Sensor detection ranges are calculated by re-running the PROPR model with the appropriate radar-target parameters for each necessary target-aircraft altitude combination.

The PROPR model offers three methods to define detection thresholds. Display option three calculates radar detection thresholds based on user input radar system and target parameters. To fully specify the radar system and environmental conditions, the user is required to complete 25 input fields, these are listed in Appendix A. Many of the inputs relate to physical radar specifications. These values can be obtained from the radar's technical documentation. A number of the input data require careful interpretation to ensure that the detection threshold is correctly determined using the reverse radar-target geometry concept. These parameters are discussed in more detail below.

1. Mission Parameters

a. Radar and Target Heights

In PROPR, the height of surface vessels and surveillance aircraft must be represented as a single numeric value. A consequence of reversing the aircraft-target geometry is that the radar height field will be a measure of the ship height. A single value for ship height is obtained by assuming the vessel's entire RCS is concentrated at a point one third of the way up the superstructure (NCCOSC Technical Document 2648, 1994, p. 35). The altitude of the aircraft is assigned to target height.

b. Radar Cross Section

When an accurate surface vessel RCS is not known, the approximation described in Chapter II should be used. EREPS represents complex target RCS' as a point source. Therefore, the effect of initial target aspect is not considered in the determination of detection range. This assumption is valid for determining the maximum detection range, however it is increasingly less accurate with decreasing range.

The SW Case field refers to the Swerling Case (SW) models. Swerling postulated four models to assess the effects of fluctuating cross section on radar detection. Within EREPS the SW models have been condensed to two options. The fluctuating model should always be selected when using PROPR.

c. *Probability of Detection and Probability of False Alarm*

The Probability of Detection (P_d) and Probability of False Alarm (P_{fa}) combine to determine the radar signal to noise ratio. The value assigned to P_d reflects a desired level of system performance, typically this is in the range 0.5 - 0.99. P_{fa} determines the number of false alarms per radar scan. This gives an indication of the load on the post detection processor (human or computer). P_{fa} is chosen to be sufficiently low to maintain an acceptable load on the post detection processor. P_{fa} values normally range from 10^{-1} - 10^{-16}. The default value for PROPR is 10^{-8}.

d. *Elevation Angle*

The value assigned to the radar elevation angle should correspond to the depression angle settings associated with the aircraft's radar.

2. Environmental Parameters

PROPR determines the atmospheric effect on EM propagation based on the input values for the evaporative duct height, surface duct height, surface refractivity, absolute humidity, and wind speed. Ideally these values should be obtained from an observation of current meteorological conditions within the intended Area of Operations (AO). This data may be available from meteorological observation stations or cooperating air and surface platforms operating in the area .

If current meteorological data is not available, the EREPS SDS program provides world-wide annual averages of the required environmental input parameters. This data is accessed by selecting the Marsden square that best covers the AO. The annual averages should only be used when a better estimate of the local meteorological conditions is not available. Detection predictions based on annual averages will provide an average detection probability for that area in lieu of the detection probabilities that exist at the time the surveillance mission is flown.

E. PROPR LIMITATIONS

The input parameter restrictions on radar height necessitated the use of reverse target geometry. Similar restrictions on other input parameters place the following limits on the range of tactical scenarios that can be modeled:

- the altitude of the patrolling aircraft must be less than 30,000 feet; and
- surface vessel size is constrained by the RCS upper bound of 99,999 square meters.

All EREPS models assume a horizontally homogenous atmosphere. This assumption implies that the meteorological conditions within the AO are uniform throughout the whole area.

IV. AIRBORNE SURVEILLANCE MODEL

The airborne surveillance simulation model is the core element of the decision aid. The model uses aircraft sensor and physical performance data, and mission specific parameters to construct an estimate of surveillance effectiveness for different sized search areas. This chapter provides a detailed examination of the framework which ensures the model accurately simulates an airborne surveillance mission.. The chapter covers the surveillance scenario, selection of measures of effectiveness, aircraft sensor and movement characteristics, and the statistical tools used to evaluate model data. A description of the computer hardware requirements and start-up procedures is provided in Appendix B.

A. NPS PLATFORM FOUNDATION

The surveillance model is constructed on the NPS Platform Foundation. The Foundation conveniently provides the tools to model military platform engagements and is readily adapted to support a wide variety of models where platforms, sensors, humans, tactics, and information flow are important. The Foundation supports an automatic, portable, animation capability where platforms are represented as animated icons, with animated range rings associated with each active, mounted sensor, moving on a zoomable map (Bailey, 1994, p. 3). Based on the object-oriented language MODSIM-II, Foundation code consists of over 17,000 lines of MODSIM and 3,000 lines of C.

In a typical military scenario, platforms require the capability to move, detect other platforms, fire weapons and much more. These generic platform capabilities are provided by the Foundation's PlatformObj, SensorObj and WeaponObj. Using these objects as a cornerstone, application-specific objects like radar, ships and aircraft can be constructed and tailored to meet the modeler's requirements.

For every sensor in the simulation there exists a VirtualSensorObj for each target the sensor might possibly detect. The VirtualSensor computes the time the host platform gain's detection, achieves CPA and loses detection against a specific target. Detection and CPA event timings are updated each time the target or sensor's host platform changes navigation characteristics. This scheduling methodology is much more efficient than

repeatedly checking each platform-target pair to determine if the detection status should be updated.

By design, the Foundation does not provide the methods to control tactical interactions. The modeler must furnish each platform with the tactical methods that enable it to receive detection information, evaluate it, and respond appropriately. Application specific objects can employ inherited platform capabilities as primitive elements in their tactical methodologies.

The automatic animation capability is one of the Foundation's greatest strengths. During the construction of the simulation, animation provides an invaluable tool to aid debugging of otherwise highly complex interactions. Afterwards, animation can be used to provide a window into the internal model mechanics to explain how the model works and how platform interactions occur. Animation has a highly detrimental effect on the speed of the simulation. If animation is not required the user can select a "no graphics" option at the start of the simulation.

B. SURVEILLANCE SCENARIO

1. Search Area and Mission

The surveillance model evaluates an open water surveillance scenario with the aircraft operating in a square shaped patrol area clear of all land mass. No restrictions on EM radiation or movement are placed on the aircraft. The aircraft is assumed to perform it's mission overtly. Limited covert posturing can be incorporated by employing a low optimum patrol altitude.

The surveillance mission is conducted with the aim of locating and then identifying as many surface vessels as possible. The purpose of the mission will determine the level to which detected targets must be identified. Typical identification requirements include:

- generic type: e.g., merchant vessel, military combatant, fishing vessel, etc.;
- class of vessel: e.g., cruise liner, Kiev CGN, etc.;
- vessel employment: e.g., whaling, seiner, trawler, etc.;
- vessel nationality or port of registration;
- vessel name.

The maximum range that the aircraft can remain from the target to achieve the desired level of identification is dependent on the type of onboard equipment used to perform the identification (e.g., eyeball, infra-red, radar profiling, etc.) and the prevailing environmental conditions. Similarly, there may exist a maximum altitude above which an aircraft is unable to make an identification. This is frequently the case when vessel classification by nationality or name is required. The surveillance model incorporates these requirements by forcing the aircraft to close and if necessary descend, before an identification maneuver is considered successful.

2. Surface Vessel Density and Dispersion

The number of surface vessels in the search area combined with the mission identification requirements have an enormous impact on the aircraft's Speed Of Advance (SOA) through the area. Each deviation from the planned patrol track to identify a target reduces the SOA while the aircraft transits to the identification range and descends to the identification altitude. If no further targets have been detected the aircraft then climbs and transits back to resume the patrol track.

Surface vessel density is determined by the characteristics of the geographic area in which the surveillance mission will take place. Higher densities can be found in coastal regions, narrow waterways, fishing grounds and along shipping routes. Many areas contain surface vessels of different sizes. The surveillance model categorizes surface vessels as either small, medium or large and permits a unique density to be entered for each size.

At the start of the simulation the surveillance model uses the vessel density and area size to calculate the number of vessels of each type that are present in the search area. The number of vessels could be evaluated deterministically or as a random variable based on a Poisson distribution. If samples are drawn from extreme points of the Poisson distribution the resulting estimates of surveillance effectiveness may be inaccurate. To avoid this situation the deterministic approach is used. Vessels are randomly distributed throughout the area using a uniform distribution. Each vessel is assigned a random course

and speed. The uniform distribution from which speed is drawn depends on the vessel size. These parameters reflect the appropriate range for each vessel class and are tabulated in Table 1.

Vessel Size	Speed Range (knots)	
	Lower Bound	Upper Bound
Small	0	12
Medium	4	16
Large	12	22

Table 1. Vessel Speed Parameters

The number of vessels within the search area remains constant throughout the replication. If a vessel reaches the boundary of the search area it is removed from the plot under the premise that only targets within the area are of interest to the searcher. Simultaneously, a new vessel of the same size as the vessel that has departed the area, appears at a random point on the boundary of the area. This vessel is a new, unidentified target that is assigned a random course (with the constraint that it must transit through the area) at the speed of the previous vessel. This methodology models surface traffic patterns over an area where vessels are constantly transiting through a region.

C. SURVEILLANCE MEASURES OF EFFECTIVENESS

The aim of this decision aid is to provide the aircraft mission planning authority with an assessment of aircraft surveillance effectiveness over varying size search areas. To compare and rank outcomes from alternative courses of action (e.g., changing patrol altitude, track spacing, or the primary sensor) surveillance effectiveness must be quantified. The quantitative indicator must be consistent, measurable and credible.

Two Measures Of Effectiveness (MOE) have been developed to evaluate surveillance performance. Both are individually evaluated for each vessel category; small, medium and large. The first MOE calculates the percentage of targets detected and is expressed as

$$\text{MOE1} = \frac{\text{number of targets detected}}{\text{number of targets in the area at start time} + \text{number of targets to enter the area}}$$

This MOE has an immediate intuitive interpretation and is simple to calculate. The drawback of this assessment of search effectiveness is the inability to differentiate between the detection opportunity against vessels that spend a short time in the search area and vessels that are in the area for a long period. An example of this situation is displayed in Figure 6. With this MOE all vessels are considered to be equally detectable regardless of the vessel transit path.

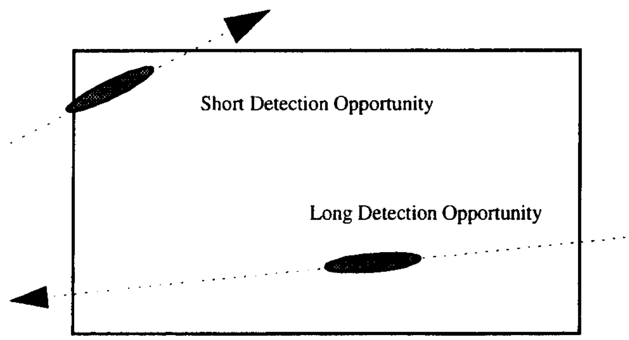


Figure 6. Vessel Detection Opportunities.

The second MOE weights the detection of a vessel with the time spent by the vessel in the search area. This quantity is summed over each detected vessel and then divided by the total time spent in the search area by all vessels, detected and undetected. The equation for the MOE is

$$\text{MOE2} = \frac{\text{total time spent in search area by detected targets}}{\text{total time spent in search area by ALL targets}}$$

The latter MOE places a greater weighting on those vessels that spend a longer time period in the search area. If the aircraft does not detect a vessel which cuts the corner of the area, the assessment of search effectiveness will decrease but to a lesser extent than is the case with MOE1. The disadvantage of the time-based MOE is that it is less intuitive and requires an accompanying explanation to clarify it's meaning.

By design, both MOEs are quantitative assessments of search effectiveness. Additionally, the values for each are statistically independent between replication runs.

This enables a confidence interval to be calculated on the mean value of each MOE, thereby providing the decision maker with an assessment of the quality of the result.

No attempt has been made to combine the two MOEs into a single value for search effectiveness. To do so would require a relative weighting of the importance of each effectiveness measure. The appropriate weighting depends on the tactical situation and is best left to the decision maker who can combine the MOEs based on "experience and judgment." To facilitate direct comparison the two MOEs are simultaneously presented in graphical form at the completion of the simulation.

D. SENSOR MODELING

1. Detection Rule

The surveillance model employs the definite range law of detection (Koopman, 1946, p. 20) to model sensor performance. Under this law detection is guaranteed when the target range is less than a critical range R and there is no possibility of detection when the range is greater than R. The expression cookie cutter detection rule is often used to describe this method of sensor modeling. Criticism of the cookie cutter model is based on the argument that the existence of a critical detection range is extremely rare. Even when the physical conditions make detection possible it is not inevitable that detection will occur. Fluctuations in the performance of detection equipment and human operators can exert powerful influences on the probability of detection.

As an alternative to cookie cutter sensor modeling, lateral range curves offer a methodology to incorporate the probabilistic nature of target detection. These curves can then be used to establish a sweep width for the sensor. Unfortunately, it is extremely difficult to construct these curves as they consist of many probability measurements, where each measurement is complex to evaluate (Washburn, 1989, p. 4-2). This situation is compounded by the requirement to develop a new curve whenever the environmental conditions change.

Despite the limitations, the cookie cutter rule offers the most versatile and practical method to model sensors in this simulation. The detection ranges used by the surveillance model are functions of target vessel size and aircraft altitude. In addition to radar, the

cookie cutter rule can be applied to other surveillance sensors including visual and infra-red. This allows the surveillance model to evaluate the surveillance effectiveness of aircraft employing these alternative sensors, without requiring changes to the detection algorithms.

To limit any possible inaccuracies from the cookie cutter assumption, a value for R is required for each vessel size, and for varying aircraft altitudes. For radar surveillance scenarios, EREPS provides an excellent means to establish the maximum radar range. This value is used as R for the example scenarios analyzed in the next chapter. The decision maker has the flexibility to input values other than the maximum sensor range if desired and considered appropriate. The surveillance model requires only that the method used to determine ranges is applied consistently.

2. Sensor Modeling in Three Dimensions

The detection capabilities of an aircraft's onboard sensors change with varying aircraft altitudes. These changes result from the effects of:

- sensor range limitations;
- a changing sensor horizon or shadowing of the target;
- different atmospheric conditions.

The magnitude of these changes can be significant, and if not accounted for by the surveillance model would produce a misleading assessment of search effectiveness. The effect of a horizon change can be demonstrated with a simple example. Consider an aircraft that is conducting a radar surveillance mission at 5000 ft. The radar horizon against a target with it's RCS centered at 60 ft is 98 nm. Should the aircraft descend to 1000 ft the horizon range will reduce to 49 nm, half the original range.

The surveillance model updates aircraft sensor ranges each time the aircraft transits across a 1000 ft altitude band i.e., at 1000 ft, 2000 ft, 3000 ft etc. If the aircraft is climbing, the detection range associated with the adjacent higher altitude block is set on crossing the changeover altitude. Figure 7 demonstrates how sensor ranges change with altitude.

The simulation program uses an altitude dial to display the current altitude of the aircraft, and to indicate changes in the aircraft's vertical movement. Sensor range changes are displayed graphically as the aircraft maneuvers. The radius of the range ring is the detection range of the sensor at the current altitude block against the largest size vessel. When the sensor detects a vessel, the range ring associated with the sensor changes color from green to red and remains red until no targets are within the sensor's range.

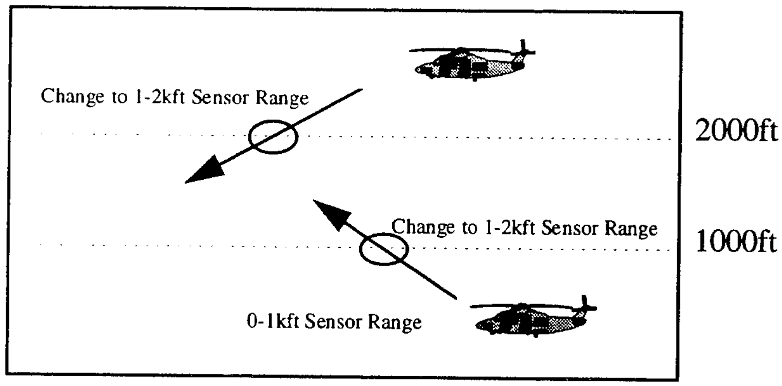


Figure 7. Sensor Range Changes with Altitude.

When a sensor range change is ordered the model re-evaluates the detection status of all surface vessels to determine the current vessel detection state. To ensure valuable vessel track information is not lost, the aircraft simultaneously maintains a record of those vessels that it has previously detected that are not yet identified. This methodology emulates the function of a manual or computer-aided tracking system maintained by aircraft to assist with the compilation and management of the surface plot.

E. SEARCH PATH

The pattern employed by the aircraft to sweep through the search area is based on a methodology associated with exhaustive inspection. This path is commonly referred to as a lawn mower path. The track consists of an ordered sequence of maneuvers to ensure consistent surveillance effort over the entire search area. Patrol altitude is preset to the user input patrol altitude.

The distance between each longitudinal leg and the spacing from the search area boundary is determined by the decision maker via the Track Spacing input variable. Figure 8 shows the relationship between the search path and track spacing. The surveillance effectiveness of a patrol mission can vary dramatically with different track spacing values. This parameter will be discussed in greater detail in the Mission Options section, however it is important to note that track spacing will be a function of sensor performance and vessel detection priorities.

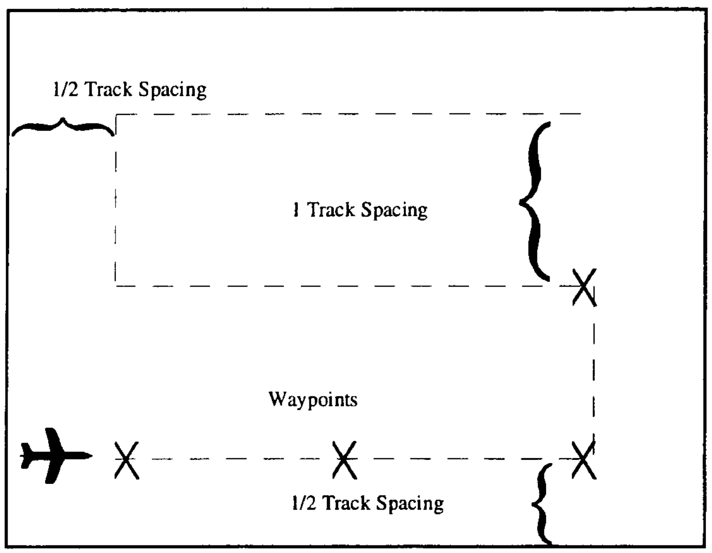


Figure 8. Search Path Geometry.

Each latitudinal leg is partitioned by a sequence of way points. The distance between way points is one track spacing. As the aircraft executes each segment of the search path it removes the current segment and way point from the path In the event the aircraft detects a vessel that is unidentified, it will leave the baseline search path and maneuver to conduct the identification. After the identification is achieved, if no further contacts require identification, the aircraft will re-execute the baseline search path and fly to the next *remaining* way point. Should the aircraft reach the end of the patrol track before it's endurance has expired it will reconstruct the original path, return to the initial way point and continue the search.

The surveillance model fine tunes the baseline search path to minimize the amount of search effort that occurs outside of the search area. The length of the last longitudinal leg is adjusted to ensure the final latitudinal leg remains one half track spacing from the area boundary. If the search area dimensions are less than one track spacing the position of the latitudinal leg is adjusted such that half the area falls on either side of the track.

The stated aim of the decision aid is to assess the effectiveness of airborne surveillance over a variety of search areas. Search areas are represented by the dimensions of the encompassing boundary. The surveillance model first calculates the dimensions of the maximum and minimum search area and then partitions the interval into equal length segments. The number of segments will determine the number of search areas for which surveillance effectiveness will be estimated. This value is input by the decision maker.

The area that an aircraft can patrol is dependent on the aircraft's patrol speed, endurance, track spacing and the surface vessel density. The maximum realistic patrol area is calculated by assuming the aircraft is never required to deviate from the lawn mower path. Under these assumptions the distance traveled by the search aircraft along the baseline track will equal patrol speed times endurance (stated in minutes). Geometric methods are then used to determine the dimensions of a square which encompass the lawn mower path.

The smallest search area of interest is calculated using results developed by Washburn (1989, p. 8-6) for exhaustive inspection. The average length of travel required to sweep out a baseline of length L, for a channel of width W, when vessel density is η per unit area, and the sensor detection range is W/2 (in the surveillance model W = Track Spacing) is

$$L + (WL\eta)\left(\frac{W - Maximum\ Identification\ Range}{2}\right) \tag{4}$$

since $WL\eta$ targets on average have to be identified and the average deviation from the base track (coming out and going back) is (W - Maximum Identification Range)/2. The average length of travel cannot be greater than the maximum distance the aircraft can fly

(patrol speed times endurance). We can solve for the baseline length L by equating the two expressions. The equation WL gives the rectangular area swept - a square of equal area has dimension $\sqrt{WL}$. This last approximation, although somewhat crude, is sufficient to determine the dimensions of the minimum search area that should be evaluated.

F. INTERCEPT AND MANEUVERING METHODOLOGY

1. Approach to the Search Area

The aircraft's geographic point of entry to the search area is an important initialization condition that will determine the sequence of detections and identification maneuvers subsequently flown by the aircraft. The starting point for a surveillance mission is not a fixed point on the boundary of the search area. When transiting to the area an aircraft will employ it's sensors to ensure they are optimized for the prevailing conditions and to gain information on the surface traffic movement in the vicinity of the search area. If the aircraft detects a vessel located in the area it will maneuver as required to commence identification procedures. Therefore, the point of entry to the search area is dependent on sensor range and the position of vessels near the boundary of the area. The surveillance model duplicates this pre-search phase of a surveillance mission by having the aircraft close from outside the area with an active sensor. If a detection is achieved the aircraft will maneuver accordingly and commence a descent if required. Onstation time does not start to elapse until the aircraft enters the search area.

2. Target Selection Criteria

When a target is detected the aircraft evaluates the time required to identify the target if an identification maneuver is commenced immediately. If the time required is less than the time remaining on the current identification path, the aircraft will discontinue the current maneuver and change to the new target. Time calculations are based on the time required to intercept a target. Intercept times are used in preference to selecting the target that is closest in range because it incorporates the effects of target motion by using relative closing velocities. This is important when the searching aircraft does not enjoy a substantial speed advantage over the target e.g., a 90 knot helicopter and a 35 knot ship. The sequence of evaluations performed by the aircraft following the detection of a vessel

and at the end of a successful identification maneuver are outlined in the tactical decision trees presented in Figures 9 and 10.

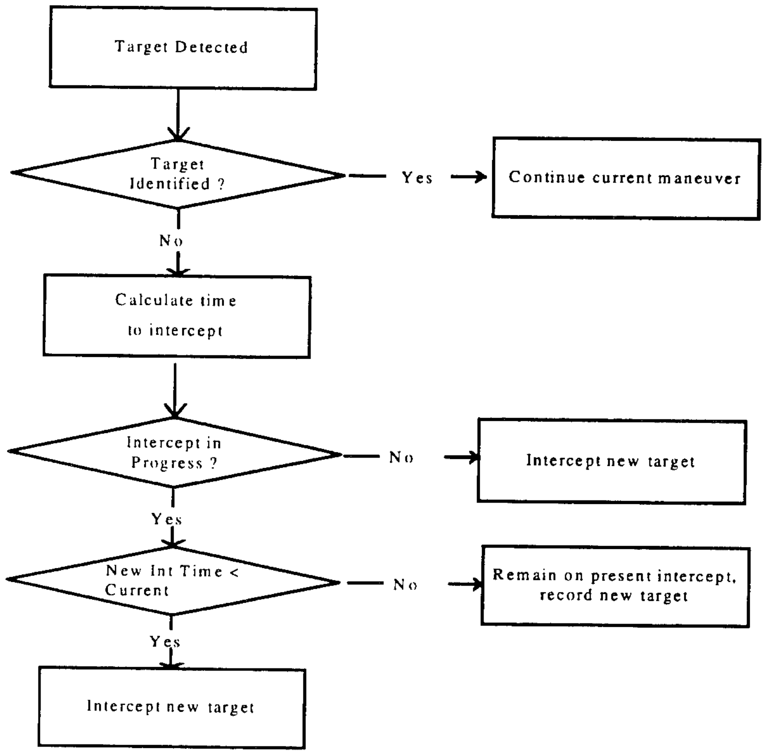


Figure 9. Pre-Intercept Decision Tree.

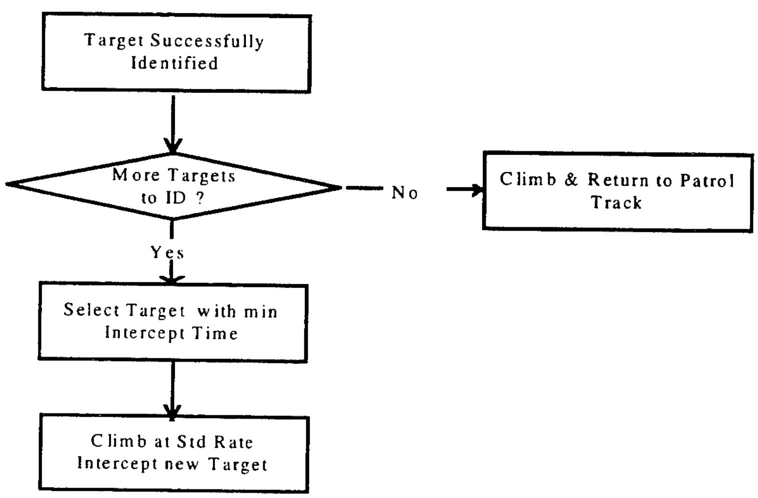


Figure 10. Post Intercept Decision Tree.

3. Descent Criteria

The lawn mower path is flown at an altitude that is a balance between the higher altitudes needed to optimize sensor range and the increased fuel consumption (hence shorter patrol time) resulting from the repeated requirement to change altitude to achieve the required level of identification. The patrol altitude is input by the decision maker and is selected based on experience and a knowledge of the aircraft's performance characteristics. Additionally the user is required to assign the aircraft a standard climb and descent rate and a maximum descent rate. For all climb and descent maneuvers the aircraft's speed through the air is held constant at the patrol speed. Speed over the ground varies according to the cosine of the climb/descent angle.

To maximize sensor performance the aircraft will remain at the pre-determined patrol altitude for as long as possible. When an identification maneuver is executed the surveillance model computes the range from the target vessel that the aircraft can close before it needs to commence a standard-rate descent. If the detection occurs at a short range such that the standard descent rate is insufficient, the aircraft can descend at a rate up to but not exceeding the maximum descent rate. Should the required rate be greater than the maximum, the aircraft will continue to close the target while conducting a maximum rate descent until the identification altitude and range requirements are satisfied.

The aimpoint for the intercept is offset from the target position to exploit the ability of the aircraft to identify the target once it is within the identification range and altitude. The intercept point, as shown in Figure 11, is set at the maximum identification altitude and is moved in the direction of the closing aircraft at a range equal to the identification range.

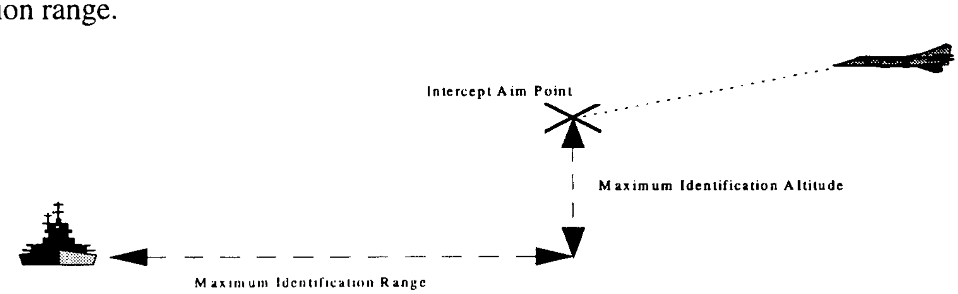


Figure 11. Intercept Aim Point.

Both the intercept course and the descent position are periodically updated during the intercept.

4. Post Identification Climb Criteria

On the completion of an identification maneuver the aircraft will evaluate all the contacts that it has detected but not identified to determine the target with the shortest intercept time. If there are no detected and unidentified targets the aircraft turns to close the next way point and performs an immediate climb at a standard rate to regain the patrol altitude. If an identification maneuver is ordered, the aircraft turns to the new intercept course and commences a standard-rate climb. The climb is maintained until a point midway between the previous and next intercept aim point is reached. At the mid-point the aircraft commences a descent to the next target. This maneuver improves sensor range during the transit between targets and observes fuel economy measures.

G. DATA COLLECTION AND STATISTICAL ANALYSIS

The purpose of the detection model is to provide estimates of aircraft surveillance effectiveness by calculating values for both surveillance MOEs for a variety of different size search areas. To achieve this the simulation employs a single factor experiment methodology where the factor is the dimension of the search area and the levels range from the minimum search area dimension to the maximum. The number of levels is pre-determined by the decision maker at the start of the simulation. Increasing the number of levels will result in the surveillance effectiveness being evaluated at a greater number of points between the minimum and maximum dimensions.

At each level, a single replication consists of one run of the surveillance scenario. The scenario commences with the random placement of surface vessels followed by the aircraft's approach to the search area. It completes when the aircraft's endurance has expired. At the end of the run numeric values for the proportion of targets detected (MOE1) and the transit time weighted proportion (MOE2) are calculated for each target vessel category. For the next replication the surface vessels are re-positioned to new random start locations and the process is repeated. The values obtained for each MOE for each replication are independent, identically distributed random variables, since different

runs use independent random numbers and the same initialization rule (Law and Kelton, 1991, p. 529). An unbiased point estimator of the mean $\hat{U}(n)$ of each MOE is obtained by averaging the results from all of the replications.

The number of replications conducted at each level is not fixed. Replications continue until the Confidence Interval (CI) for both MOEs are within the bounds established by the decision maker. Performing replications until the half-interval width is smaller than the desired absolute error ensures that the minimum number of replications are conducted to achieve the desired accuracy and that for a given probability the maximum error can be specified in advance. A confidence interval for the mean MOE value is formed using a t-distribution and the sample variance $S^2(n)$. The formula for a 95 percent CI ($\alpha = 0.05$) is

$$\hat{U}(n) \pm t_{n-1,0.975} \sqrt{\frac{S^2(n)}{n}} \tag{5}$$

Sequential procedures are utilized to efficiently update $\hat{U}(n)$ and $S^2(n)$ as each replication is completed. Law and Kelton (1991, p. 539) suggest that at least ten replications are necessary to ensure the CI coverage is close to the desired $100(1-\alpha)$ percent accuracy. In the surveillance model replications are continued until the above error condition is satisfied and at least ten runs are conducted. When these two conditions are met the estimate of the mean value of both MOEs for the current level is recorded. The simulation then conducts the appropriate reset actions for the next level and recommences replications. When all levels are completed, the MOE means are displayed graphically on two line charts. To provide the user with a continuous indication of the status of the simulation, a graphic box displays the number of levels completed, the total number of levels required, and the replication count at the current level.

H. AIRCRAFT, SENSOR, AND MISSION OPTIONS

From conception the surveillance model was designed to estimate surveillance effectiveness for a wide variety of aircraft/sensor combinations and mission requirements. Model versatility is achieved by allowing the user to manipulate a series of data files to

adjust performance and mission parameters to suit the desired scenario. Data input formats and units are defined in Appendix C.

1. Aircraft Parameters

An aircraft is defined by specifying the patrol speed, onstation time in the search area, and climb/descent rates. This approach allows the model to be used for any airframe or propulsion type including jet or propeller fixed wing, helicopter, or airships. The icon used in the animation to represent an aircraft always resembles a fixed wing aircraft, regardless of the user input performance parameters.

2. Sensor Parameters

Sensors employed by the aircraft determine surface vessel detection and identification ranges and the maximum identification altitude. The model does not require details on the type of sensor used to perform these functions. A permissible detection sensor is any sensor where the sensor's detection range can be expressed as a function of vessel size and aircraft altitude. Sensors in this category include radar, eyeball, Infra-Red (IR), and Low Level TV (LLTV). If the aircraft has multiple sensors capable of making detections, the range associated with the most capable sensor for the particular target-vessel/altitude combination should be used.

The surveillance model is capable of providing an assessment of surveillance effectiveness for a variety of environmental conditions. EREPS was used as a means to revise *radar* detection ranges when anomalous EM propagation conditions exist. Range data for other sensors can be appropriately adjusted by the decision maker to account for conditions that impact sensor performance. This includes low visibility caused by night, haze, fog, rain etc.

3. Mission Parameters

Variable mission parameters provide the capability to adjust the traffic densities to suit the geographic region of interest, modify vessel detection priorities, and establish the acceptable margin of error for surveillance effectiveness estimates. Mission profiles can be fined tuned by altering the optimum patrol altitude to encompass the requirement to observe altitude restrictions imposed by air safety de-confliction zones, covert operations,

and weather. If appropriate, a defacto loiter period can be introduced to allow an additional time delay for each identification maneuver. This is accomplished by reducing the maximum identification range, thereby forcing the aircraft to spend more time in the vicinity of each target.

The discussion on the aircraft's search path introduced a track spacing variable. This parameter is used to construct the baseline path employed by the aircraft to sweep through the search area. Increasing track spacing increases the distance between successive latitudinal search legs. This distributes the aircraft search over a greater area, resulting in a search pattern which is more extensive but less thorough. To achieve high levels of surveillance effectiveness the numeric value assigned to track spacing should reflect the detection capability of the aircraft's sensors and the vessel detection priorities.

When conducting a surveillance mission an aircraft will optimize sensor performance by flying the majority of the patrol at the designated patrol altitude. The detection capability of the aircraft at this altitude is the starting point for determining the optimal track spacing. Vessel detection priorities are established when the mission tasking authority nominates the vessels that have priority for localization and identification. If the aim of the mission is to monitor territorial fishing zones to prevent illegal fishing activities, then track spacing is based on the detection range for small vessels when at the patrol altitude. In this case, setting track spacing to twice the small vessel detection range would be appropriate. If the track spacing used is greater than this distance, gaps will exist in the surveillance coverage. A smaller track spacing will increase the probability of detection within the searched area, however, the area patrolled will be a smaller size. A similar argument can be applied if the mission priority is to detect vessels in the medium or large size category.

When the tasking authority requires the aircraft to locate and identify vessels from more than one category, the surveillance model provides the ability to explore the impact of various track spacing distances on surveillance effectiveness. Detection ranges for the priority targets establish the track spacing lower and upper bounds. Multiple runs of the

surveillance model can then be performed using different track spacing distances to compare surveillance effectiveness against surveillance coverage.

I. MODEL LIMITATIONS

The surveillance model provides an assessment of surveillance effectiveness for missions where an exhaustive search of the patrol area is desired. The exhaustive search tactic is not suitable for all surveillance scenarios. If the size of the search area is very large alternative baseline search paths may achieve a higher proportion of detected targets. Before using this model the tasking authority should consider whether exhaustive search is an appropriate tactic for the mission.

The model does not have the capability to incorporate physical characteristics that are unique to the proposed search area. Considerable further programming effort is required if the model is to represent features such as fishing banks, shipping corridors, or any situation that restricts or concentrates the movement of shipping within the area.

The search areas evaluated by the model are all square shaped. The primary influence of the shape of the area is to determine the aircraft's baseline search path. If required the model could be expanded to consider other search area geometries. Modifying the shape of the search area and the aircraft's path is straightforward and can be accomplished without any changes to the algorithms used to control aircraft and vessel interactions.

In the current configuration the maximum identification range is a single value that is applied to all vessels independent of vessel size. This assumption is reasonable when the mission requirement is to identify vessels by name, nationality, or port of registration. These levels of identification cannot be achieved without closing to within close proximity of any vessel. If identification by type or generic class is sufficient, then different maximum identification ranges may be appropriate.

The time available to the aircraft to patrol the search area is based on an assessment of aircraft endurance provided by the decision maker. This approach could be

refined by basing onstation time on fuel consumption. This would require software modifications to implement:

- initial fuel availability;
- consumption rates for climbing, descending and level flight.

V. SCENARIO EXAMPLES

Three case studies are presented in this chapter to demonstrate the diversity of scenarios to which the surveillance model can be applied. The aircraft used in these examples are based on an unclassified representation of the primary maritime surveillance aircraft employed by the Royal Australian Navy. The geographic locations used in these scenarios are depicted in Figure 12. Each scenario is analyzed to investigate model characteristics, strengths, and limitations.

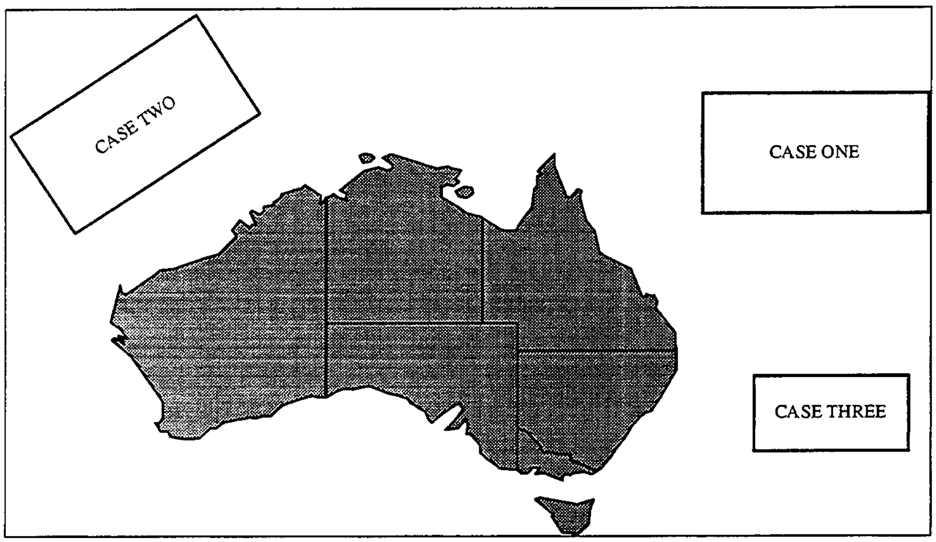


Figure 12. Scenario Geographic Locations.

A. CASE STUDY ONE

1. Mission

HMAS ADELAIDE (FFG01) has been tasked to locate and monitor two frigates from Orangeland who are operating to the north east of Australia, possibly in support of Orangeland space-vehicle re-entry activities. Previous attempts to detect the frigates have been unsuccessful due to their dispersed formation and close proximity to a busy fishing ground. ADELAIDE has available an embarked utility helicopter (AS350B) capable of visual search only. The search will be conducted in daylight with 30 nm of visibility and a

cloud base at 2500 ft. No large vessels operate in these waters, however, the presence of some medium size merchant vessels is anticipated in addition to the frigates.

2. Aircraft and Sensor Data

A complete listing of the aircraft, sensor, and mission parameters for this scenario is provided in Appendix D. The key parameters of interest are summarized below:

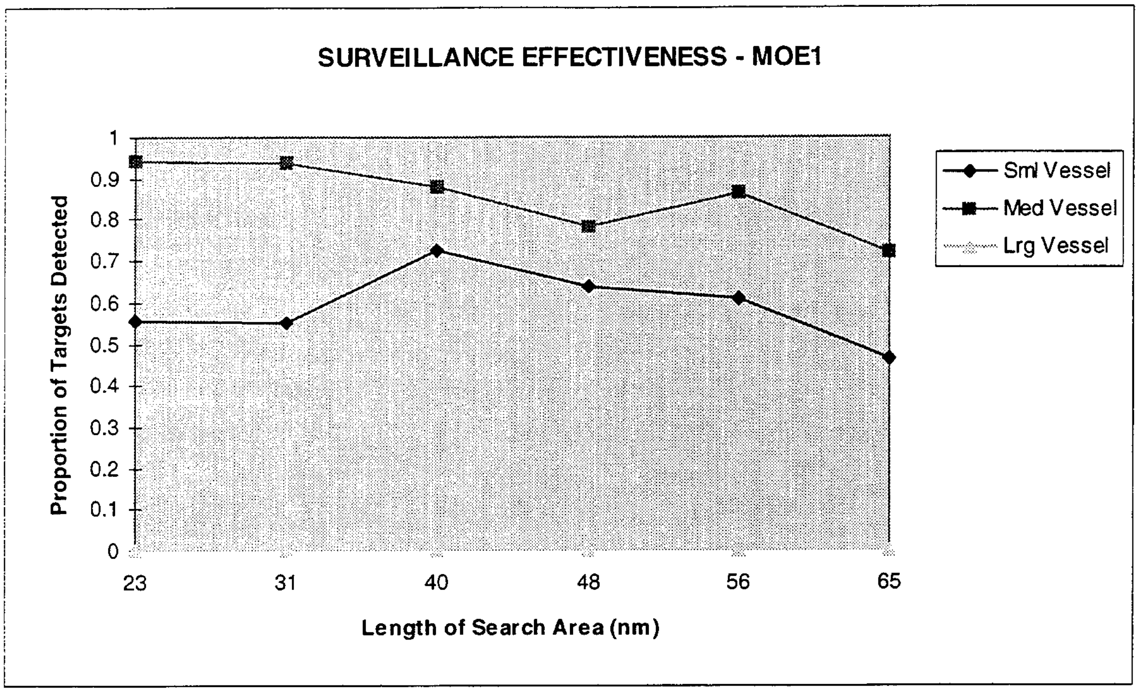
- aircraft patrol speed - 90 knots;
- aircraft endurance - 100 minutes;
- optimal patrol altitude - 1500 ft;
- primary sensor - visual;
- track spacing - 24 nm (based on a detection range of 12 nm against medium size vessels).

3. Analysis of the Results

The output of the surveillance model is shown in Figure 13. The immediate impression from the charts is that the assessment of surveillance effectiveness provided by both MOEs is almost identical. For each area the proportion of targets detected when weighted by transit times (MOE2) is greater than the unweighted proportion (MOE1). The difference is at most 0.12 (at 23 sq. nm) and decreases in magnitude as the size of the search area increases. This result is consistent with the characteristics of the time weighted proportion. MOE2 is designed to account for the different detection opportunities presented by each vessel, particularly those who have short transit distances through the search area. This event is more likely to occur when the size of the search area is small.

The higher surveillance effectiveness achieved against medium size vessels is logical. Track spacing is optimized for this category because the priority targets are medium sized vessels. This enables the aircraft to fully exploit it's detection capability by searching a larger area than would be possible if small targets were also a priority.

When using the output charts the decision maker must be cautious about drawing conclusions from minor deviations or changes in slope between point estimates. The confidence interval for each estimate must be considered when assessing the possible



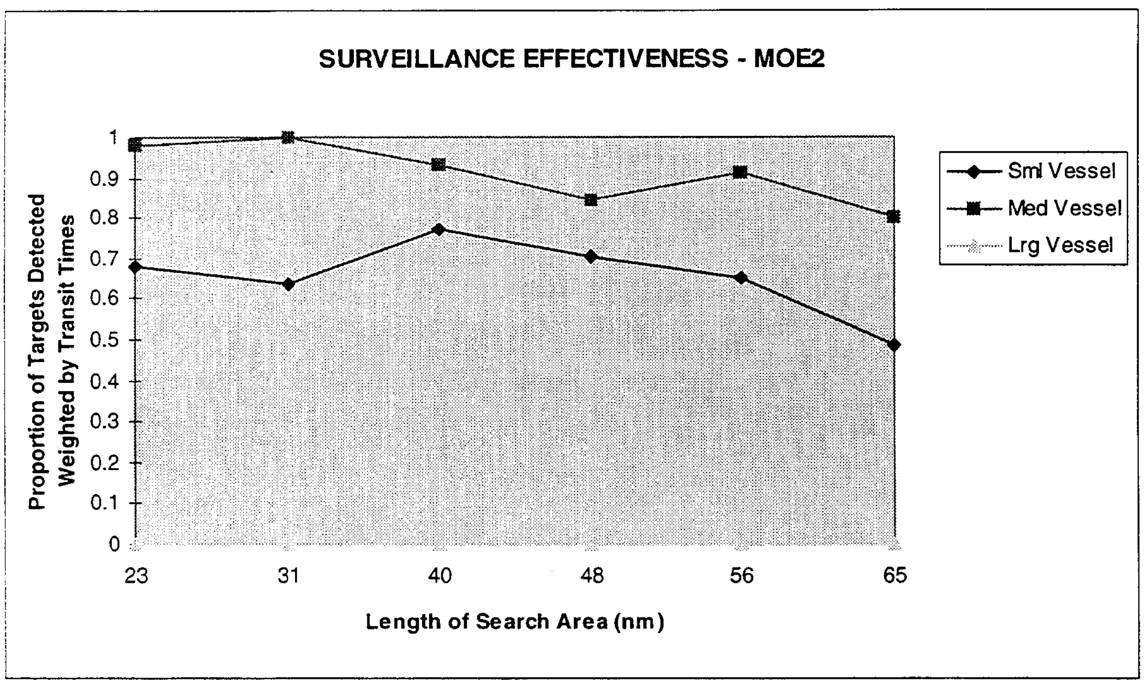
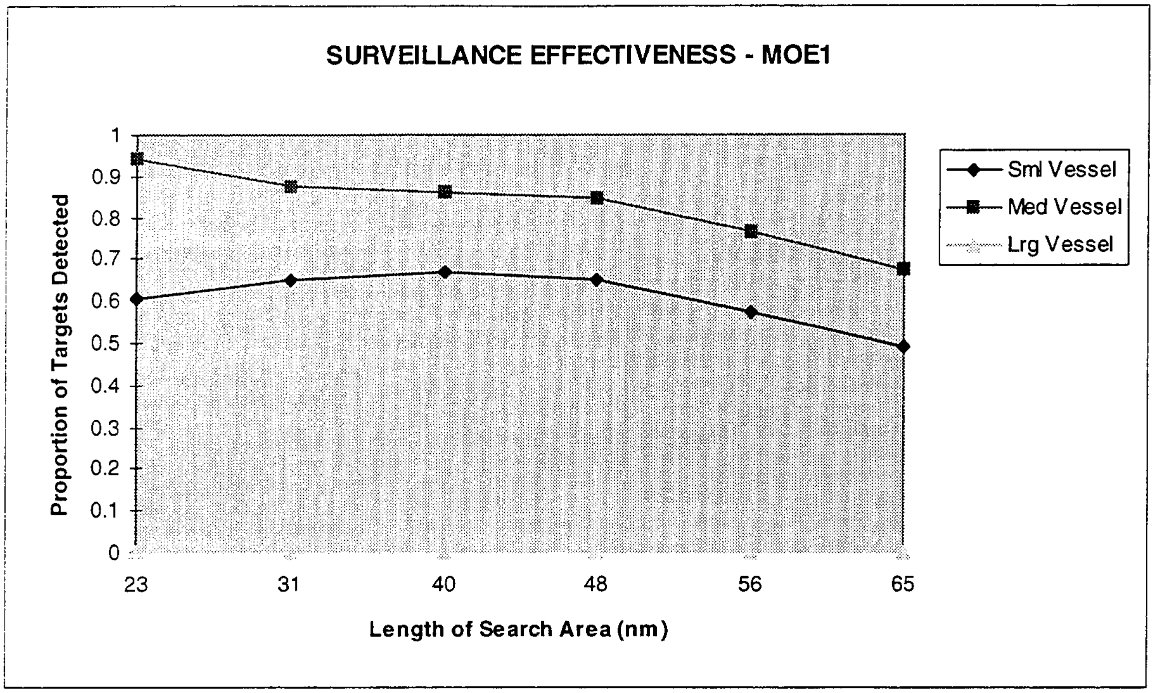


Figure 13. Estimates of Surveillance Effectiveness - Helicopter Visual Search.

cause of spikes or troughs in estimate values. The apparent drop in surveillance effectiveness for medium sized vessels at the 48 sq. nm area is an example of this situation. If further investigation of possible trends or anomalies is required, the interval between assessment points should be reduced or the confidence interval decreased and the model re-run. This scenario was re-evaluated using a confidence interval half width of 0.03 in place of the original 0.1. The resulting estimates of surveillance effectiveness shown in Figure 14 indicate a trend that appears more realistic than the first assessment. To achieve this refined solution the number of replications performed by the model increased by up to eight times.

Both MOEs indicate that surveillance effectiveness within each vessel category does not change dramatically over the different size areas. This intriguing result is due to the short sensor detection range and low speed of the aircraft. If a small search area is assigned to the aircraft the potential for vessels to have short transits within the search area before reaching the boundary increases. This raises the difficulty of detecting then identifying vessels within the short detection opportunity. Accordingly, surveillance effectiveness may initially increase as the size of the search area increases. This is the case for small vessels in the first MOE of Figure 14. For larger areas the incidence of targets transiting through and out of the area before they can be identified decreases; however, the number of targets and the distance between the targets and transit times increases.

In this scenario the answer to the search area assignment problem will depend on an assessment of how accurately the search area can be placed. The weighted MOE can be used to provide a measure of search effectiveness if the placement of the search area is sufficiently accurate to ensure the detection opportunity against the frigates is reasonable. If scant information is available on the location of the frigates, then a larger area (56 sq. nm) may offer the best trade off between increasing the size of the area covered without unacceptably reducing the potential to locate the targets.



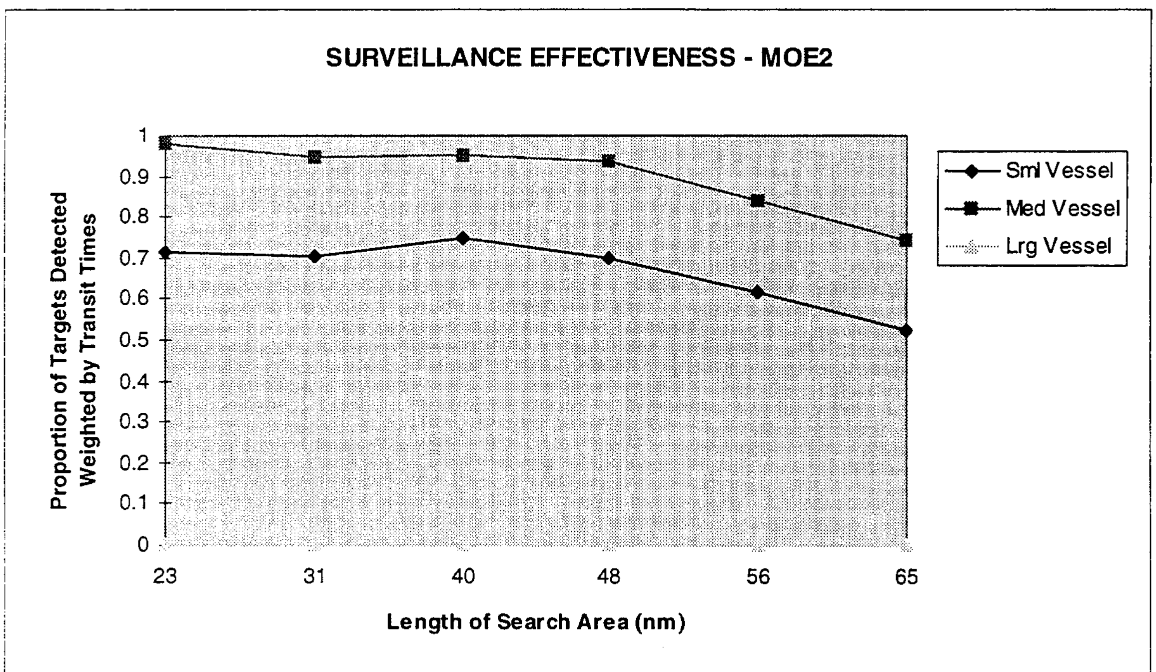


Figure 14. Estimates of Surveillance Effectiveness - Helicopter Visual Search (Reduced CI).

B. CASE STUDY TWO

1. Mission

Intelligence reports have indicated that a 15,000 ton freighter suspected of carrying illegal immigrants is approaching the Timor Sea to the north west of Australia. Maritime Headquarters has been directed to deploy sufficient assets to conduct surveillance on all approaches to possible disembarkation points. HMAS DARWIN (FFG04) with an embarked SH70B helicopter has been detached from a routine exercise to participate in the operation. Planning onboard DARWIN is underway to determine optimal organic aircraft employment so that additional resources can be requested if required. The search will be conducted in an area with heavy traffic patterns associated with a number of shipping lanes.

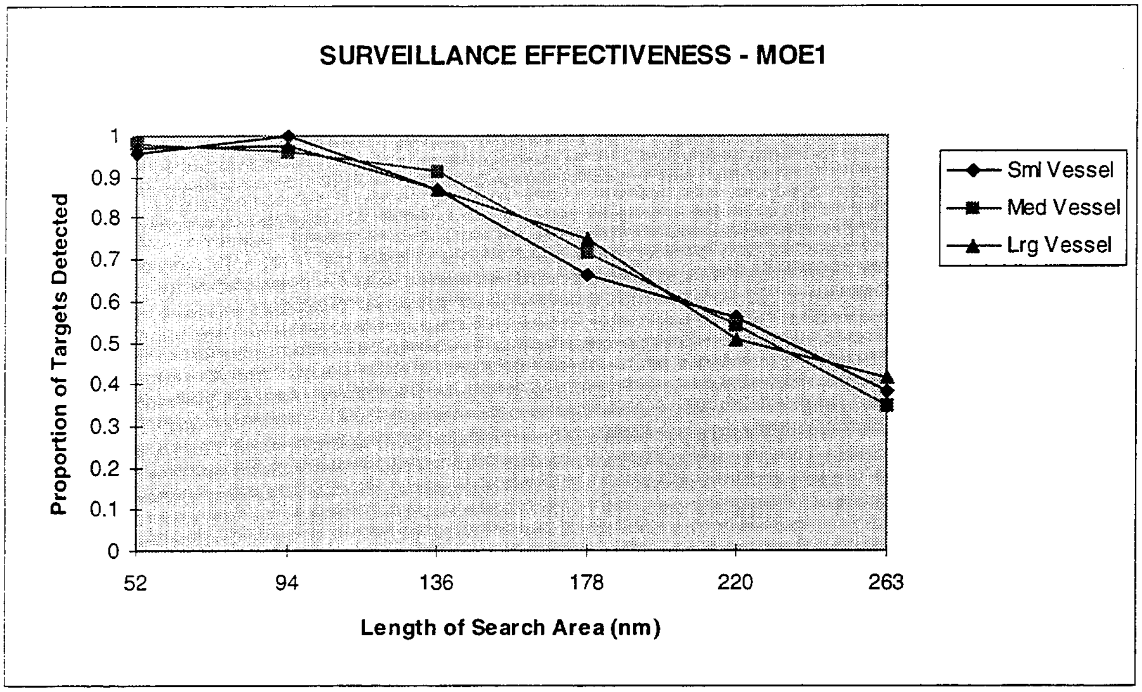
2. Aircraft and Sensor Data

An accurate prediction of aircraft sensor performance based on the forecast environmental conditions, is a critical input to the surveillance model. This scenario is evaluated in good and poor weather to demonstrate the important prediction capability provided by EREPS for radar surveillance. For the first run, the search is performed in favorable conditions. In the second run, tropical weather conditions have deteriorated with the wind increasing to 50 knots (sea state six), the cloud base has descended to 2500 ft, and the humidity is higher. A complete listing of the aircraft, sensor, and mission parameters for this scenario is provided in Appendix D. The key parameters of interest are summarized below:

- aircraft patrol speed - 140 knots;
- aircraft endurance - 3.25 hours;
- optimal patrol altitude - 3500 ft (good weather), 2000 ft (poor weather);
- primary sensor - radar;
- track spacing - 120 nm (good weather), 80 nm (poor weather).

3. Analysis of the Results

The output of the surveillance model for the good weather conditions, is shown in Figure 15. As with the previous scenario, the time weighted proportion of detected



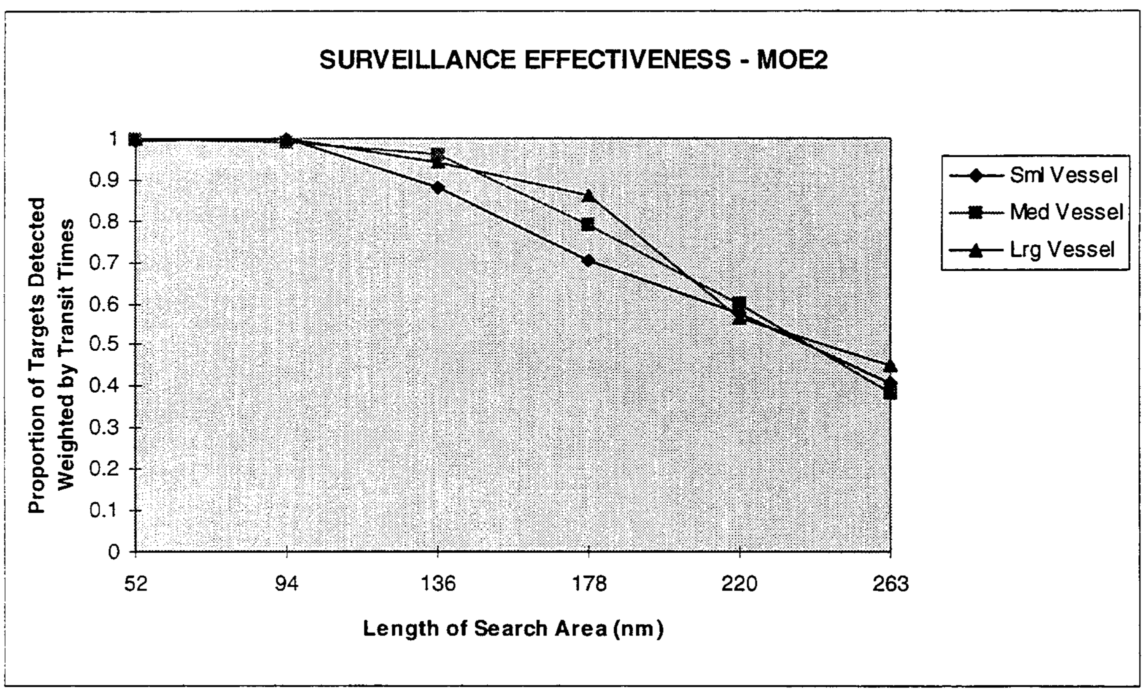
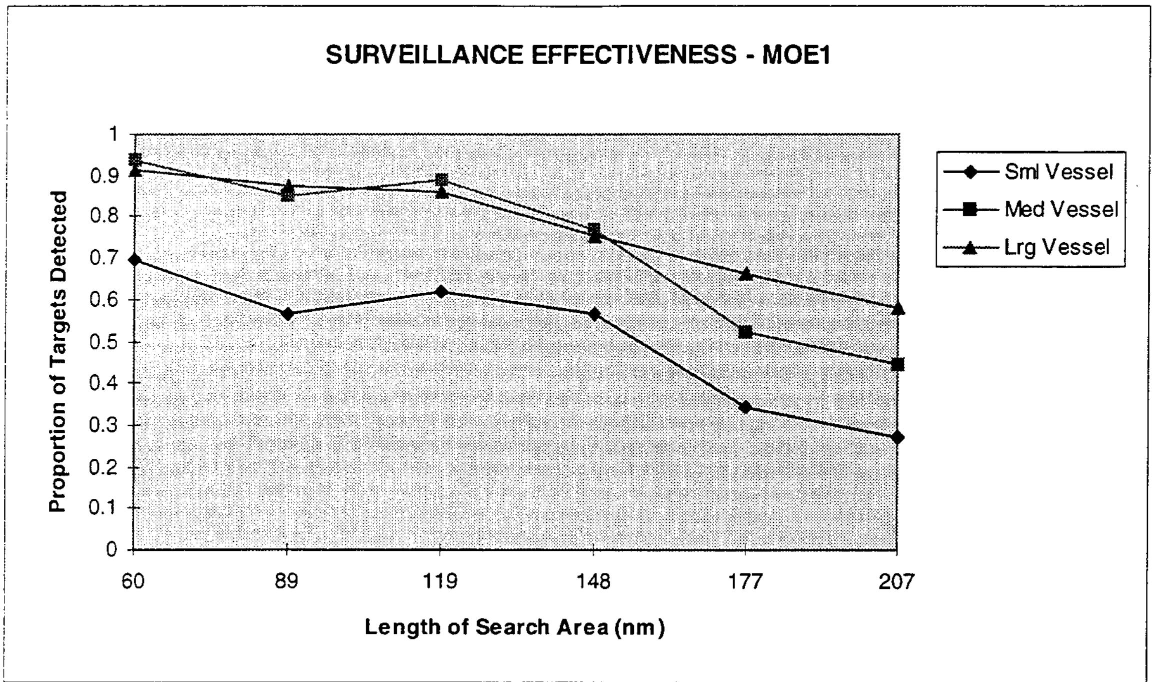


Figure 15. Estimates of Surveillance Effectiveness - Helicopter Radar Search (Good Weather).

targets (MOE2) is higher than the unweighted proportion. The difference is greatest for large vessels due to their higher speed and therefore potentially shorter detection opportunity. Again, as the size of the area increases the magnitude of the difference decreases. The trend displayed by both MOEs is consistent in showing a decreasing surveillance effectiveness as the size of the search area increases. Although the track spacing was selected to optimize the detection of medium sized vessels, it is also a good compromise for simultaneously detecting and monitoring large and small vessels. This may be important if the freighter is expected to rendezvous with other vessels.

For the second run, the mission requirements were maintained, only the weather conditions were altered. Track spacing was reduced from 120 nm to 80 nm due to the reduced radar detection capability. The results for this run are displayed in Figure 16. The output shows a reduction in surveillance effectiveness against all vessels. For small vessels the reduction is dramatic. This reflects the significant detrimental effects of higher sea states on radar detection, when the RCS of the target is small. Although the impact of the sea state reduces with increasing vessel size, the effects are clearly important for all vessels when the size of the search area is large.

Without the combined use of EREPS and the surveillance model, a quantitative assessment of search effectiveness in the given conditions is almost impossible. Using the information supplied by the model, DARWIN will have a good estimate of the search capability of it's organic helicopter and will be able to request appropriate support. When the ship is advised of the availability of additional airborne assets, the surveillance model can again be used to assess the search effectiveness of these aircraft to ensure the search effort is efficiently allocated and coordinated.



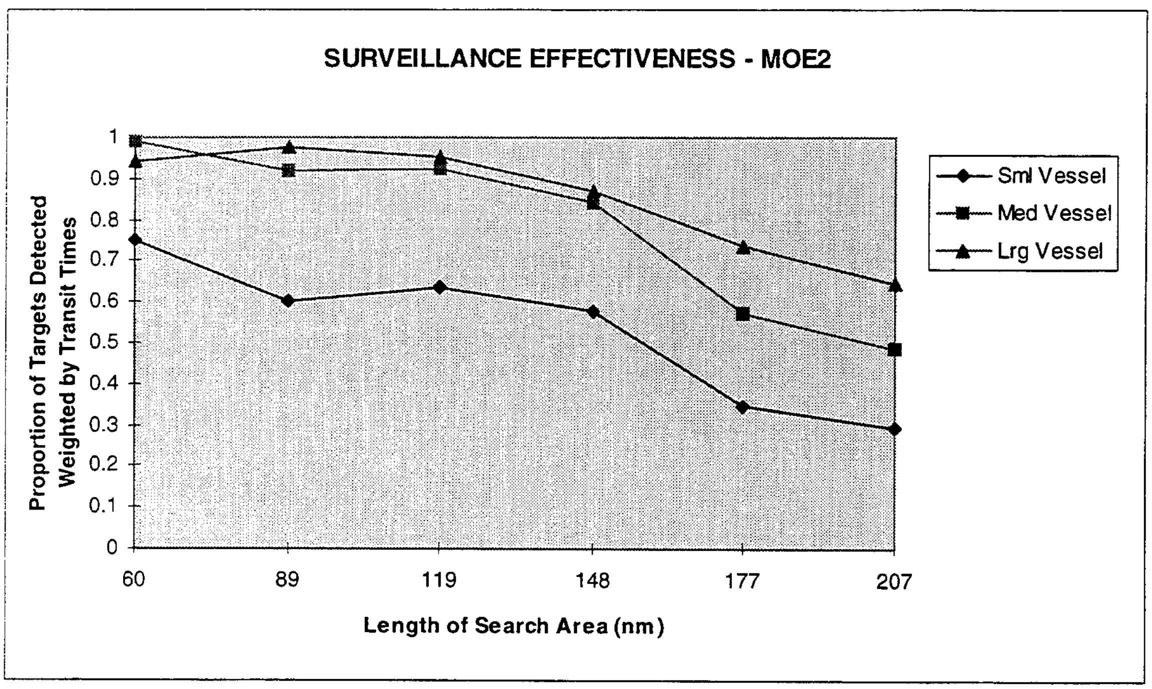


Figure 16. Estimates of Surveillance Effectiveness - Helicopter Radar Search (Poor Weather).

C. CASE STUDY THREE

1. Mission

A mobile sea range missile firing exercise is scheduled to take place in 36 hours in the Tasman Sea off the east coast of Australia. An area of water has been selected clear of major shipping routes to minimize the danger to shipping. In addition to a warning promulgated via Notice to Mariners, a P3C will conduct range clearance operations to locate and warn vessels by radio to leave the area. The aircraft's squadron has been advised that a small number of trans-Tasman merchant traffic and recreational sailing vessels may be in the area. A thorough search of the range is required to ensure the firing exercise can take place.

2. Aircraft and Sensor Data

The presence of a surface based duct up to 1000 ft will result in extended radar detection ranges when the aircraft is below this altitude. EREPS was used to provide a quantitative assessment of the magnitude of the ducting effect to ensure the detection range data reflected the improved sensor performance when flying at this altitude. Sea state and wind conditions are favorable for radar surveillance. A complete listing of the aircraft, sensor, and mission parameters for this scenario is provided in Appendix D. The key parameters of interest are summarized below:

- aircraft patrol speed - 280 knots;
- aircraft endurance - 8 hours;
- optimal patrol altitude - 4000 ft;
- primary sensor - radar;
- track spacing - run one 140 nm, run two 90 nm.

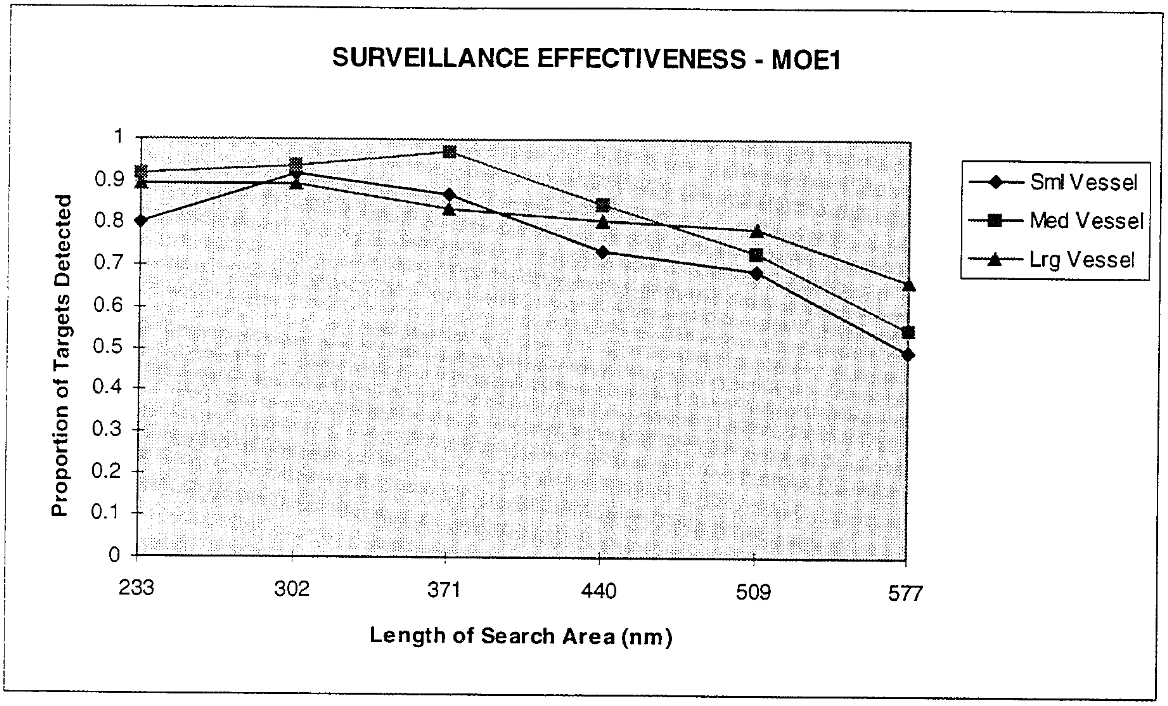
3. Analysis of the Results

To explore the impact of the track spacing variable on surveillance effectiveness, this scenario was evaluated with two different track spacing distances. For the first model run, the track spacing was set to 140 nm to take advantage of the aircraft's long detection ranges against medium and large vessels. The estimates of surveillance effectiveness shown in Figure 17 indicate that reasonable coverage is achieved against all targets for

area sizes up to 371 sq. nm. Beyond this value the effectiveness of the aircraft to locate and warn medium and small sized vessels begins to decline. The decision to use a track spacing which favors the detection of medium and large vessels has increased the potential size of the search area at the expense of reducing the aircraft's ability to locate smaller vessels.

For the second model run, the track spacing was reduced to 90 nm to improve the surveillance effectiveness against small vessels. This immediately reduced the maximum size area from 577 sq. nm to 458 sq. nm. Figure 18 shows the re-evaluated estimates of surveillance effectiveness. With the smaller track spacing, the search effectiveness against small vessels is now very good out to an area of 380 sq. nm and is higher than any single estimate when the larger track spacing is used. Within 380 sq. nm the improvement for small vessels is achieved without adversely effecting the ability of the aircraft to locate and warn medium and large vessels. Some degradation in the search coverage against the larger vessels is apparent when the size of the search area is increased beyond 380 sq. nm. This is because a greater proportion of the aircraft's endurance has been expended locating small vessels that were previously undetected.

In this scenario the purpose of the surveillance mission is to locate all vessels within the danger area rather than any specific vessel or vessels. The vessels at greatest risk are those who have long transits in the firing area. The surveillance effectiveness against these vessels is best estimated by the proportion of targets detected weighted by transit times. On this basis the P3C should use a track spacing of 90 nm and be assigned an area of 380 sq. nm. With these parameters a surveillance effectiveness of better than 0.85 is predicted. If this search area is not sufficient to cover the required danger zone, then additional surveillance assets need to be employed.



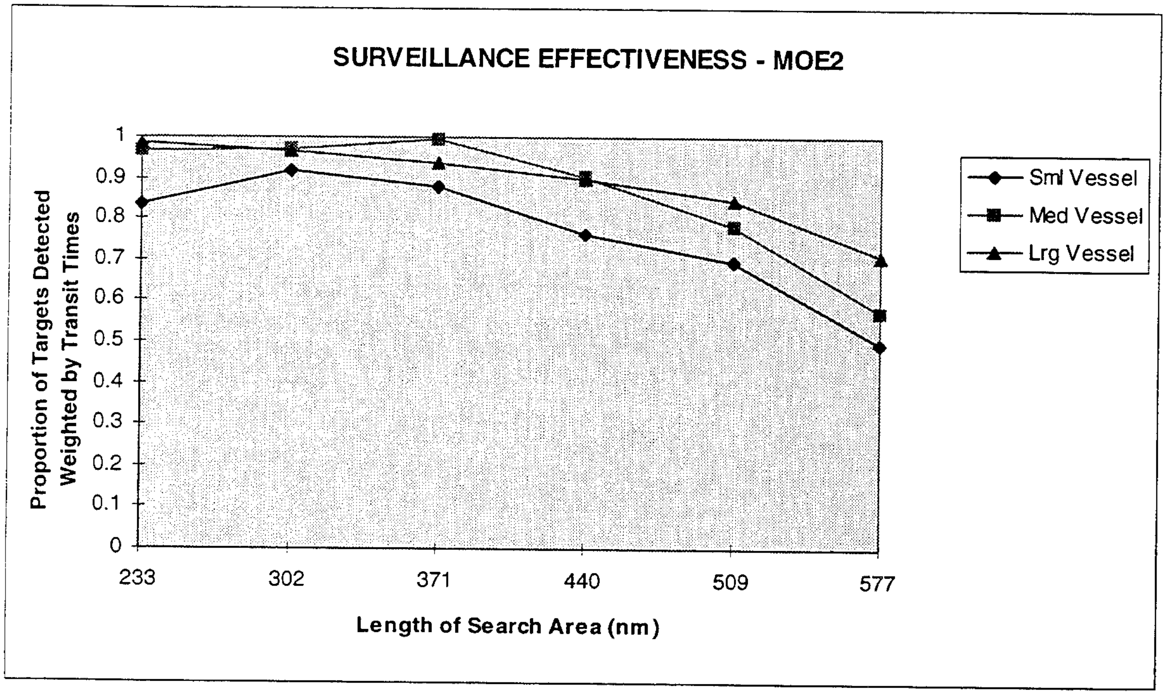
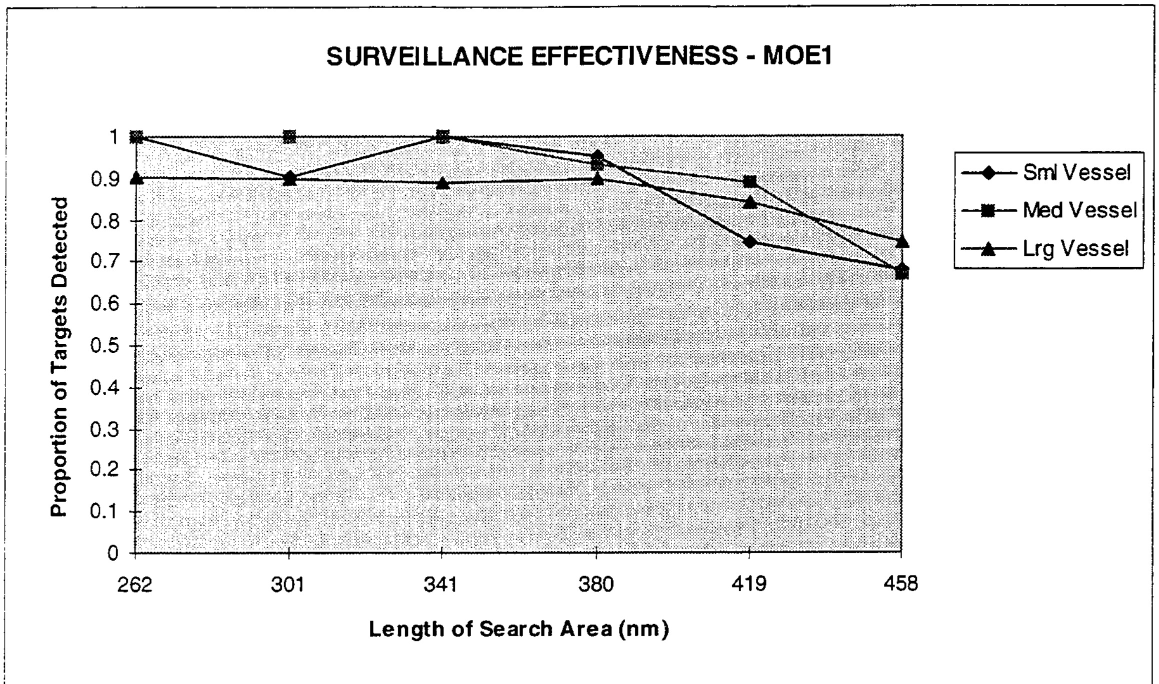


Figure 17. Estimates of Surveillance Effectiveness - Fixed Wing Radar Search (Track Spacing 140 nm).



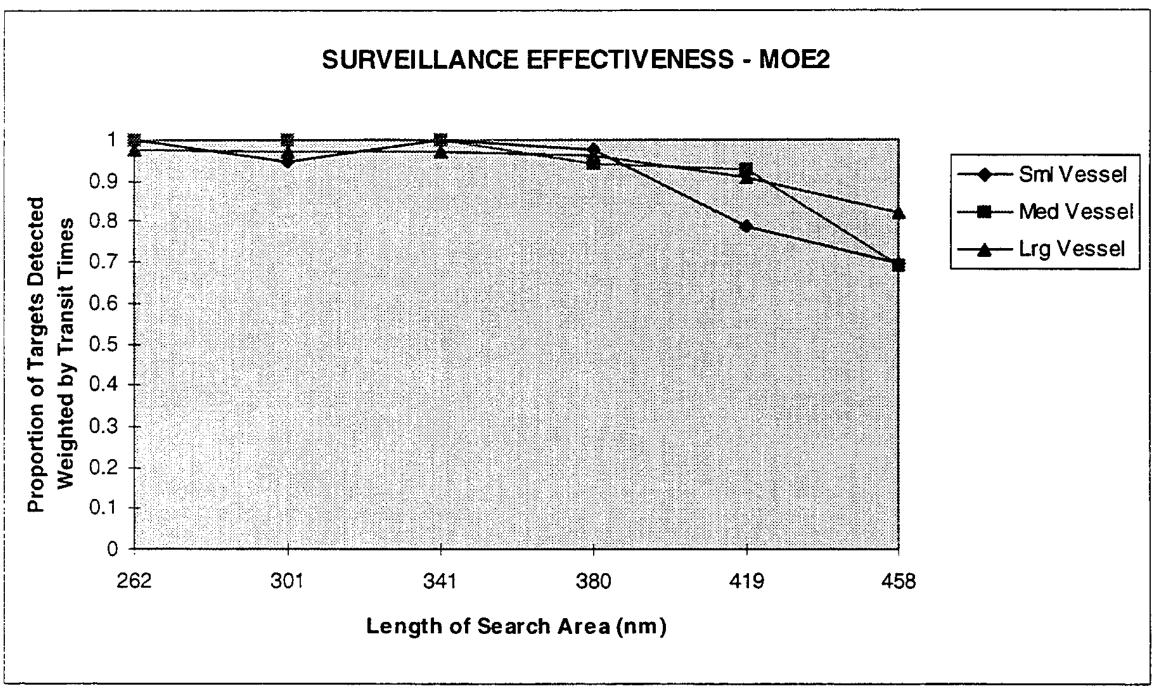


Figure 18. Estimates of Surveillance Effectiveness - Fixed Wing Radar Search (Track Spacing 80 nm).

D. VERIFICATION OF THE RESULTS

The surveillance model is unique in it's ability to accurately estimate surveillance effectiveness for a specific set of aircraft, sensor, mission, and environmental parameters. Analytic solutions to the surveillance problem adopt simplifying assumptions that do not allow them to incorporate the same diversity of factors. Accordingly, the estimates provided by the model cannot be validated by comparison with similar models. Validation can be achieved by using operational trials to confirm model results.

As an intermediate step, verification of some of the surveillance model functions can be performed by running the model on a scenario for which analytic methods exist. As discussed in Chapter I, closed form mathematical expressions can be used to evaluate the expected proportion of detected targets for the exhaustive search and random search tactics, when the following scenario constraints apply:

- the detection range of the aircraft is constant for all vessel sizes;
- sensor performance is independent of aircraft altitude;
- target vessels are stationary;
- no new vessels enter the search area.

The surveillance model aircraft search path is based on an exhaustive search pattern with the additional requirement to perform target visitation (identification). Thus the path of the aircraft is less efficient than an exhaustive search without visitation and is more structured than a random search pattern. This implies the proportion of targets detected by the aircraft should be bounded above by the proportion that would be detected using exhaustive search and bounded below by the results from a random search. This comparison provides a means to test whether the model's underlying search, detection, and visitation algorithms perform as expected.

For an exhaustive search the expected proportion of detected targets after t hours of search is

$$\begin{cases} \dfrac{v\,W\,t}{A} & \text{for} \quad t \le \dfrac{A}{vW} \\ 1 & \text{for} \quad t > \dfrac{A}{vW} \end{cases}$$

v = speed of the aircraft, knots
A = search area, nm
W = sweep width of aircraft sensor, nm

The equivalent formula for random search is

$$1-\exp\left(\frac{-Wvt}{A}\right) \qquad t \geq 0$$

The aircraft speed, v, used for the random search calculations is adjusted to account for the slower Speed Of Advance (SOA) resulting from the visitation policy. The corrected SOA is calculated by dividing the distance traveled in sweeping an area of length, L, using exhaustive search, by the equivalent distance traveled to sweep the same area using exhaustive search with visitation (Equation 4). This fraction is then multiplied by the aircraft speed. The formula for the corrected speed is

$$\frac{L}{L+(WL\eta)\left(\frac{W-\mathit{Maximum\ Identification\ Range}}{2}\right)} * V$$

η = vessel density per unit area

A test scenario was run with the following parameters:

- v = 90 knots, $v_{\text{corrected}}$ = 51.4 knots;
- t = 1 hour;
- η = 0.005.

The results from the analytic computations and the surveillance model for a range of areas are shown in Figure 19. Although these results cannot prove the search algorithm performs correctly, they do provide evidence to suggest that the implemented methodologies provide credible results.

The animation capability of the model provides an additional means to intuitively verify that the searching aircraft executes it's mission by employing logical tactics. An example of the animation display is shown in Figure 20. The display shows:

- expended mission time;
- aircraft altitude in thousands of feet;
- a plan view of the entire search area with the location of the aircraft and all surface vessels;
- a range ring for the detection sensor;
- the replication count.

This level of information is sufficient to investigate the interactions between the aircraft and surface vessels under a wide variety of scenarios and conditions.

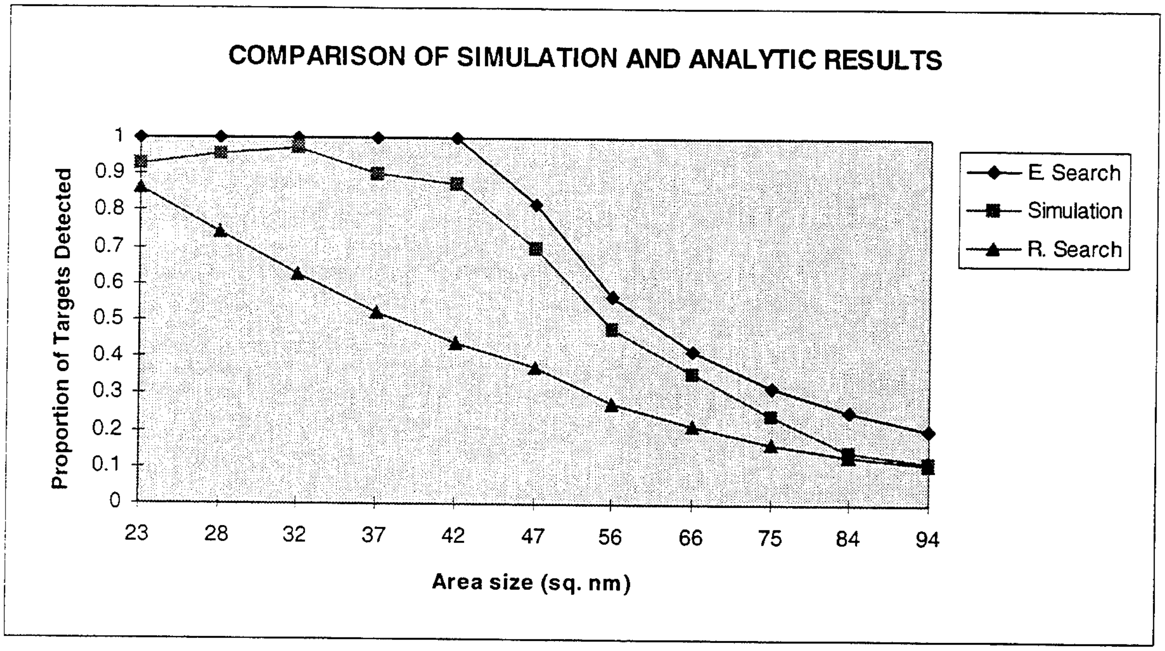


Figure 19. Comparison of Simulation vs. Analytic Results.

The author believes the estimates produced by the model are reasonable. This assertion is based on experience as a seagoing officer who has directed the employment of aircraft on many maritime surveillance missions. Over a series of extensive tests the model has consistently produced estimates of surveillance effectiveness that appear appropriate to the scenario under evaluation.

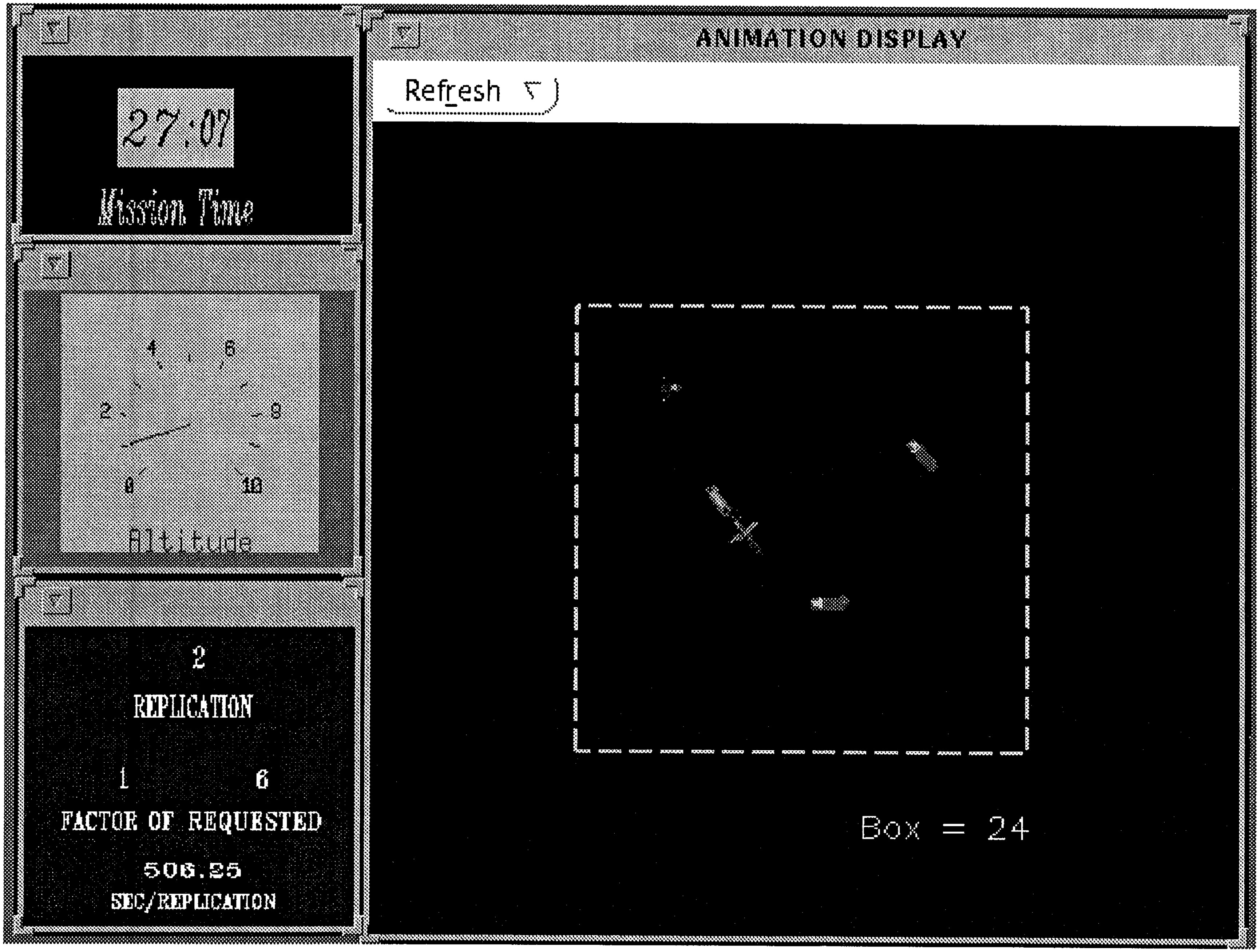


Figure 20. Surveillance Model Animation Display.

VI. RECOMMENDATIONS AND CONCLUSIONS

The ability to conduct maritime surveillance effectively, is vitally important for countries like Australia that are surrounded by vast expanses of water. Aircraft are the optimum platform to detect, localize, and identify surface vessels over large areas. Mission planning based on valid performance estimates is an essential element for effective utilization of these expensive assets. Two decisions made during the planning of a mission considerably impact the potential for success. These decisions are:

- the selection of a geographic region for the search;
- the allocation of a search area within this region, that is commensurate with the aircraft's movement and sensor capabilities.

These two factors cannot be considered in isolation. Intelligence resources are used to solve the first problem. This thesis provides a decision aid that addresses the area allocation problem using the surface traffic and environmental characteristics of the selected location.

The principle element of the decision aid is a surveillance model constructed on the NPS Platform Foundation. It uses simulation to provide quantitative estimates of surveillance effectiveness, to a level of accuracy and sophistication not previously available. Surveillance estimates based on two MOEs are calculated using mission specific aircraft, sensor, and scenario information. One MOE calculates the proportion of targets detected. The second weights the proportion of targets detected by the detection opportunity presented by each target. Both MOEs are evaluated for each vessel size (small, medium, and large) and for a variety of different sized search areas. While the two MOEs are not independent, they do provide a different evaluation of surveillance effectiveness, and allow the tasking authority the option of selecting the appropriate measure for the mission. After all model runs are completed, the two MOEs are presented graphically as a function of search area size. This facilitates the selection of the correct area size to achieve a desired level of surveillance effectiveness or provides a measure of the aircraft's surveillance effectiveness for a given sized search area.

The simulation accurately models the critical phases of a surveillance patrol with realistic aircraft performance and search methodologies. Sensor performance and aircraft movement are dynamically evaluated in three dimensions. The model can be utilized for a wide variety of aircraft/sensor combinations and blue water mission scenarios. Data files allow these parameters to be changed quickly and conveniently.

Accurate forecasting of aircraft surveillance radar to determine vessel detection ranges is achieved using an innovative adaptation of the EREPS 3.0 PROPR program. This procedure ensures the sensor data used by the simulation is based on a credible estimate of radar performance in the local environmental conditions. Additionally, the model can evaluate surveillance effectiveness for sensors other than radar. Examples include visual, IR ,and LLTV.

This thesis was motivated by the desire to construct a decision aid to replace the crude methods currently used in the Royal Australian Navy to calculate optimal aircraft search areas. The surveillance model satisfies this requirement with a simulation that is versatile, flexible, and easy to use. Future research on the model should include operational trials to further validate model accuracy.

APPENDIX A. EREPS INPUT PARAMETERS

The EREPS PROPR model estimates the radar propagation factor and radar detection thresholds using radar system parameters, target characteristics, and environmental conditions. The 25 input fields to PROPR and their units are specified below.

A. RADAR PARAMETERS

Input Parameter	Units
Frequency	Mhz or Ghz
Radar Height	ft or m
Polarization	Horizontal, Vertical, Circular
Antenna Type	Sinusoidal, Cosecant Squared, Height Finder, Gauss
Antenna Gain	dBi
Vertical Beamwidth	Degrees, Mrad
Horizontal Beamwidth	Degrees, Mrad
Scan Rate	rpm
Peak Power	Watts, Kilowatts, Megawatts, dBm
Pulse Width	ps, ms, ns, us
PRF	Hz
System Loss	dB
Receiver Noise Figure	dB
Probability of Detection	0 - 1
Probability of False Alarm	0 - 1

B. TARGET PARAMETERS

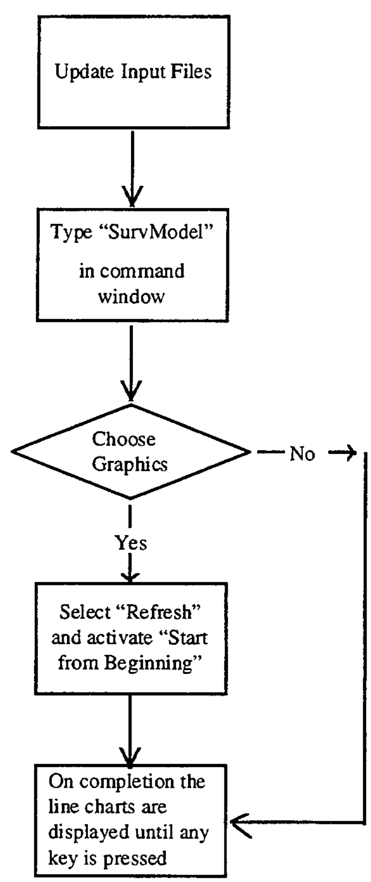
Input Parameter	Units
Target Height	ft or m
Radar Cross Section	sqm or dB

C. ENVIRONMENTAL PARAMETERS

Input Parameter	Units
Evaporative Duct Height	ft or m
Surface Based Duct Height	ft or m
Surface Refractivity	Nsubs
Absolute Humidity	g/m3
Wind Speed	knots or m/sec
K	effective earth radius

APPENDIX B. SURVEILLANCE MODEL HARDWARE REQUIREMENTS AND STARTUP PROCEDURES

The executable version of the surveillance model can be loaded and run on any Sun OS UNIX workstation with 64 megabytes of RAM. All data and graphic (.sg2 extension) files must be located in the same directory as the executable program. The sequence of events to prepare and then run the model are shown below.



APPENDIX C. SURVEILLANCE MODEL DATA FILE FORMATS

A surveillance scenario is defined by assigning appropriate values to aircraft, sensor, and mission parameters. Data files provide a convenient means to change these variables without re-compiling the main program on each occasion. To avoid input errors data files must conform to a strict syntax. General file formatting instructions are provided in a Technical Report by Bailey (1994). This appendix addresses only the data files that need to be modified by surveillance model users.

Every data file consists of a collection of records. The first entry in the file is the number of records in that file. Each record starts with a name and ends with the symbol \\. Comments are preceded by the symbol #. In the following examples, the entries which may be modified to suit the surveillance scenario are highlighted in ***bold italics***.

FILE SEARCHER.DAT

1	
SearcherSpecs ->	
3.0	# onstation time (hours)
1.5	# optimal patrol speed (nm per minute)
2.4	# optimal patrol altitude (thousands of feet)
4.5	# maximum range (nm) to achieve desired ID level
0.5	# max altitude to achieve desired ID (thousands of feet)
0.005	# average density of small vessels in a 10 nm by 10 nm area
0.12	# average density of medium vessels in a 10 nm by 10 nm area
0.06	# average density of large vessels in a 10 nm by 10 nm area
50.0	# track spacing (nm)
5	# number of points between the max and min search area at which
	# search effectiveness will be calculated
0.1	# desired absolute error for surveillance estimate (range 0.0-1.0)
\\	

FILE SENSORRANGES.DAT

3	# number of altitude bands in this file, must extend to the optimal
	# patrol altitude, additional records can be added when necessary
500FT ->	# altitude of aircraft (covers 0 - 1000 ft)
5	# max sensor range vs. small vessels (nm)
10.0	# max sensor range vs. medium vessels (nm)

14.9	# max sensor range vs. large vessels (nm)
\\	

1500FT ->	# altitude of aircraft (covers 1000 - 2000 ft)
8	# max sensor range vs. small vessels (nm)
14.0	# max sensor range vs. medium vessels (nm)
20.3	# max sensor range vs. large vessels (nm)
\\	

2500FT ->	# altitude of aircraft (covers 2000 - 3000 ft)
12.0	# max sensor range vs. small vessels (nm)
22.0	# max sensor range vs. medium vessels (nm)
31.0	# max sensor range vs. large vessels (nm)
\\	

FILE PLATFORM.TYPE

This file contains a number of data fields which are not utilized by the surveillance model, however, they are required by the underlying Platform Foundation. Only the indicated fields should be changed, the remaining entries can be ignored and should not be altered.

Aircraft ->	
Air	# realm
?	# max speed
?	# min speed
1000	# standard climb/dive rate (feet per minute)
MN	# defines units to feet per minute
?	# max fuel
?	# fuel burn rate
1500	# max dive rate (feet per minute)
?	# max turn rate
?	# standard turn rate
0	# number of weapons for the platform
1	# number of sensors for the platform
Sensor	# name of the sensor
\\	

APPENDIX D. MISSION PARAMETERS FOR THE EXAMPLE SCENARIOS

A. CASE STUDY ONE

1. Aircraft Parameters

Input Parameter	Value
Endurance	1.67 hours
Patrol Speed	90 knots (1.5 nm per min)
Patrol Altitude	1.5 Kft
Maximum Identification Range	5 nm
Maximum Identification Altitude	0.8 Kft
Standard Climb/Descent Rate	500 ft/min
Maximum Descent Rate	1200 ft/min
Track Spacing	24 nm

2. Sensor Parameters

Vessel Size	Visual Detection Range (nm) for Specified Aircraft Altitudes	
	0 - 1000 ft	1000 - 2000 ft
Small	5	7
Medium	10	12
Large	13	18

3. Mission Parameters

Input Parameter	Value
Small Vessel Density (in 10 nm by 10 nm area)	0.6
Medium Vessel Density (in 10 nm by 10 nm area)	0.1
Large Vessel Density (in 10 nm by 10 nm area)	0.0
Surveillance Estimate Confidence Interval Half Width	0.1
Number of Area Sizes Evaluated	6

B. CASE STUDY TWO (GOOD WEATHER)

1. Aircraft Parameters

Input Parameter	Value
Endurance	3.25 hours
Patrol Speed	140 knots (2.3 nm per min)
Patrol Altitude	3.5 Kft
Maximum Identification Range	4 nm
Maximum Identification Altitude	0.6 Kft
Standard Climb/Descent Rate	700 ft/min
Maximum Descent Rate	1400 ft/min
Track Spacing	120 nm

2. Sensor Parameters

Vessel Size	Radar Detection Range (nm) for Specified Aircraft Altitudes			
	0 - 1000 ft	1000 - 2000 ft	2000 - 3000 ft	3000 - 4000 ft
Small	25	29	32	40
Medium	30	41	55	61
Large	36	59	64	75

3. Mission Parameters

Input Parameter	Value
Small Vessel Density (in 10 nm by 10 nm area)	0.01
Medium Vessel Density (in 10 nm by 10 nm area)	0.033
Large Vessel Density (in 10 nm by 10 nm area)	0.017
Surveillance Estimate Confidence Interval Half Width	0.1
Number of Area Sizes Evaluated	6
Evaporative Duct Height	0 ft
Surface Based Duct Height	100 ft

B. CASE STUDY TWO (POOR WEATHER)

1. Aircraft Parameters

Input Parameter	Value
Endurance	3.25 hours
Patrol Speed	140 knots (2.3 nm per min)
Patrol Altitude	2.0 Kft
Maximum Identification Range	2 nm
Maximum Identification Altitude	0.5 Kft
Standard Climb/Descent Rate	700 ft/min
Maximum Descent Rate	1400 ft/min
Track Spacing	80 nm

2. Sensor Parameters

Vessel Size	Radar Detection Range (nm)		
	0 - 1000 ft	1000 - 2000 ft	2000 - 3000 ft
Small	13	17	20
Medium	26	34	43
Large	33	48	55

3. Mission Parameters

Input Parameter	Value
Small Vessel Density (in 10 nm by 10 nm area)	0.01
Medium Vessel Density (in 10 nm by 10 nm area)	0.033
Large Vessel Density (in 10 nm by 10 nm area)	0.017
Surveillance Estimate Confidence Interval Half Width	0.1
Number of Area Sizes Evaluated	6
Evaporative Duct Height	0 ft
Surface Based Duct Height	0 ft

C. CASE STUDY THREE

1. Aircraft Parameters

Input Parameter	Value
Endurance	8 hours
Patrol Speed	280 knots (4.67 nm per min)
Patrol Altitude	4 Kft
Maximum Identification Range	2 nm
Maximum Identification Altitude	0.5 Kft
Standard Climb/Descent Rate	1000 ft/min
Maximum Descent Rate	1500 ft/min
Track Spacing	1) 140 nm 2) 90 nm

2. Sensor Parameters

Vessel Size	Radar Detection Range (nm) for Specified Aircraft Altitudes			
	0 - 1000 ft	1000 - 2000 ft	2000 - 3000 ft	3000 - 4000 ft
Small	32	28	38	46
Medium	35	44	59	66
Large	36	56	68	79

3. Mission Parameters

Input Parameter	Value
Small Vessel Density (in 10 nm by 10 nm area)	0.0025
Medium Vessel Density (in 10 nm by 10 nm area)	0.0025
Large Vessel Density (in 10 nm by 10 nm area)	0.005
Surveillance Estimate Confidence Interval Half Width	0.1
Number of Area Sizes Evaluated	6
Evaporative Duct Height	20 ft
Surface Based Duct Height	1000 ft

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